History of Science Teaching in England

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AUTHOR'S PREFACE

THE aim of this little volume is to indicate in outline the growth of the scientific spirit in England and the relationship of that growth to the development of a system of education into which the teaching of science gradually became incorporated. The relationship has now been established not only in the Universities but also in the schools, both secondary and primary. It has been my aim to convey to the reader very briefly the facts concerning the introduction of science teaching into these three stages of education.

The original conception of the function of a university was the handing on of the heritage of knowledge. But in the later 19th century the universities became centres for research and so set themselves the task not only of nurturing young students but of providing facilities for maturer workers to extend the boundaries of knowledge. Indeed science teaching at the universities to-day is the outcome of the realization that we cannot afford to wait for the occasional unaided genius. There are so many opportunities for the trained student of moderate intellectual powers that the recognition of professionalism in knowledge has necessitated a teaching system for producing professionals.

It is at last conceded that some knowledge of science is part of what is vaguely called a *liberal education*. After a chequered career, science now enjoys an established place in the curriculum of the public schools

and of the State aided secondary schools of this country. Elementary schools now have a ration of scientific instruction though by no means such a generous one as in days gone by.

I am much indebted to Mr. A. I. Ellis of the British Museum for his kindness in correcting the proofs and for helping me many times in searching for information. I am under a debt of gratitude to Professor T. P. Nunn for the inspiration of his lectures and for his kind advice on many difficult points. Particularly my thanks are due to Dr. Charles Singer who, ever since his suggestion of the subject of science teaching as a piece of study, has generously given me his valuable criticism, advice and encouragement.

D. M. TURNER.

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Chapter I

DAWN OF THE SCIENTIFIC SPIRIT IN ENGLAND

1. *The Thirteenth Century Awakening*

DURING the earlier medieval period, the scientific spirit as we now know it, was non-existent. But while the philosophy of Greece was forgotten or suppressed in the west, some part of this treasure of learning was guarded by the Arabic speaking peoples. The knowledge was shared by Jews, Syrians, Moors and others who in their travels westward divulged some of their secrets or at least awakened the curiosity of those they met. Thus the Greek learning began to penetrate to the West during the 11th and 12th centuries. What passed for the teaching of the Greek philosophers was often distorted out of all recognition, but this dissemination from Arabic sources meant that the dark ages were giving place to a new dawn.

The first evidence of a real awakening is shown in the rise of the universities. During the early years of the 12th century, a school of medicine at Salerno attracted large numbers of students. Afterwards Bologna became famous as a centre for the study of Law, and Paris for theology. These schools may be regarded as the parent universities. Towards the end of the 12th century a number of students migrated from Paris to Oxford. There were no halls or colleges at first, so that when a

number of students felt they would like a change of surroundings, they simply settled elsewhere. In this way Cambridge was founded as an off-shoot of Oxford, and Padua from Bologna. The students were frequently mere children, and there was no supervision of their studies. Many stories are told of open battles between the students and citizens. At last the need for discipline resulted in the establishment of colleges in the 13th century.

The curriculum of the medieval universities consisted of the *Seven Liberal Arts*, Grammar, Rhetoric, Dialectic, forming what was known as the *Trivium*, together with Arithmetic, Geometry, Astronomy and Music forming the *Quadrivium*.[1] A certain standard of attainment was insisted on, a student having to present a thesis and defend it verbally before the "masters." The universities were the chief means of spreading the study of philosophy, and by the end of the first quarter of the 13th century nearly all the works of Aristotle were known in Western Europe. The chief characteristic of the universities at this time was the high place afforded to Aristotelian dialectic or logic, and the only effective discipline of a scientific order was mathematics. The expounders of Aristotle were thus led to emphasize the deductive side of mathematical reasoning to such an extent that deductive argument and logical demonstration became part of the University tradition.

The new studies and especially the works of Aristotle were not at first welcomed by the church. This hostility, however, wore off in time. In 1228 William of Auvergne, Bishop of Paris, expounded the writings of Aristotle and

[1] This classification is derived from the sixth century encyclopædic work of Martianus Capella, *The Marriage of Mercury and Philology*.

encouraged the spread of the new knowledge. From that time on the works of Aristotle came to bulk more and more largely in the curriculum. Now apart from their immediate human interest, problems of the nature, structure, origin and fate of the universe were the direct concern of the church. The great scholars of the time turned their attention to possible schemes of the universe, all more or less dependent on Aristotle. Albertus Magnus (1193—1280), the greatest scientific mind among the schoolmen declared in favour of the teachings of Ptolemy, so that the Ptolemaic system became the orthodox opinion of the church for centuries.

Thomas Aquinas, the pupil of Albertus, was a man of rare intellect, with a marvellous gift of systematic logical exposition. He set himself the task of surveying the whole field of knowledge. Holding that reason and faith were not opposed, he sought to reconcile the Greek philosophy with the teaching of the church. His defence of the Ptolemaic system and the systematization of faith and knowledge given in his *Summa Theologiæ* had an important influence on subsequent thought. The *Summa* became the basis of catholic orthodoxy. Truth was conceived, not as a growth, but as something static and complete, entrusted to the church for transmission to her children. This attitude ultimately led to a state of intellectual stagnation, but in the thirteenth century there was no lack of vigour on the part of the great schoolmen who were called to defend the bulwarks of the church. A subject *De sphaera* which treated of astronomy and the structure of the universe became part of the school curriculum and was especially studied in the well-known treatise on the subject by John Holywood (Johannes Sacrobosco flourished *c.* 1250).

It was thus not only in the rarefied atmosphere of theological discussion that an awakening spirit was felt. A similar impulse soon made itself felt in higher university studies. Thus the movement was reflected in Medicine when the Emperor Frederick ordered a translation of Avicenna to be circulated and forbade anyone to practise surgery who had not studied anatomy for at least a year. One shudders to think what surgery was like before that, for it certainly was no great thing even after! Dissection came to be practised in the universities in the 14th and 15th centuries as a recognized part of the teaching for medical students.[1] It was not, however, a scientific study as we should understand it to-day, but was simply a means of verifying or rather of remembering the teaching of Galen. As yet there was no *experimental* teaching of this or of any other subject.

The only branches of science well established at this time were astronomy and mathematics. Certain works of Ptolemy had reached Europe at the end of the 12th century through Arabic translations. The works of Euclid recovered centuries before from the library of Alexandria were translated also from an Arabic version by Adelard of Bath in the earlier 12th century and subsequently revised by Campanus of Novara. Alchemy, a direct heritage from the Arabs, inspired perhaps a certain amount of experimental study. There must have been a considerable empirical knowledge of mechanics which rendered possible the exquisite architecture of the period. The elements of algebra and trigonometry were beginning to be known in the writings

[1] Charles Singer, "A Study in Early Renaissance Anatomy" in *Studies in the History and Method of Science*, Vol. 1, Oxford, 1917, and *Evolution of Anatomy*, London, 1925.

of Alkhowarazmi whose name is commemorated in the word *Algorism*. The Arabic notation makes a first appearance. The art of winning the common metals from their ores was well recognized. Thus there was, in the 13th century, a growing body of knowledge in different fields. It was in the middle years of this century that the first English man of science, Roger Bacon (1214—1294), began his work.

2. *Roger Bacon*

Roger Bacon studied first at Oxford and then at Paris, where he lectured on Aristotle's *Physics*. On returning to England, Bacon came under the influence of the learned Robert Grosseteste, Bishop of Lincoln, who persuaded him to join the Franciscan Order. From this time onwards Bacon devoted all his time to arduous study. His subsequent writings present medieval science in its most favourable light. In his *De mirabili potestate artis et naturae* he dealt with popular beliefs in magic. Shrewd observation and common sense is shown in the way he disposes of many idle tales and shows that physical reasons may be brought forward to explain many magical tricks.[1] His *Opus Maius* and *Opus Minus* are summaries of existing knowledge and include an account of the theory of alchemy. His great encyclopædia the *Compendium Studii Philosophie* was planned so that his treatment of grammar, logic, mathematics and natural science should lead up to the queen of sciences, theology.

[1] A. G. Little, *Roger Bacon, Essays contributed by various writers on the occasion of the commemoration of his birth*, Oxford, 1914, gives the best modern account in English.

The claims of Bacon as a pioneer in scientific discoveries have often been urged too far. There is no doubt, however, that he made original contributions to scientific knowledge, particularly in the study of optics. Thus he found experimentally that segments of a spherical burning glass made small letters appear large, and he makes the definite suggestion that such segments might be used to aid falling sight. He is thus the inventor of spectacles, the use of which came in soon after his death. Despite his optical researches, however, he did not succeed in stating correctly the laws of reflection and refraction, though he realized that the apparent size of objects depends on the angle subtended at the eye. We have no evidence that he constructed a telescope or microscope, but it is true that he dimly foresaw these instruments: thus he speaks of the possibility of a lens by the use of which the sun, moon and stars could be made to appear to "descend here below."

The interest of Roger Bacon for our present purpose lies in his independence of outlook and in his emphasis on the value of direct experiment, and above all in his consciousness of the inadequacy of the scholastic educational system. In an age when the scholars of the greatest repute spent their time in endless arguments on the meaning of terms such as matter and form, and the distinction between substance and accident, Bacon was bold enough to condemn many of the controversies as fruitless. At a time when the acutest intellects were brought to bear on the problems of realism and nominalism and when deductive logic occupied the most honoured position among university studies, Bacon showed the need for a first hand enquiry by means of experiment. His teaching is summarized in the well-

known words *Sine experientia nihil sufficienter sciri potest.*

3. *The Rise of Modern Science*

The last stages of scholasticism show a degeneration into a rigid system of argument and a deterioration from the standard to which Roger Bacon aspired. As Whewell says: "The same knots were tied and untied, the same clouds formed and dissipated" and the system became a closed and formal one to which little or nothing could enter from without and it perished of inanition.

The decay of scholasticism was associated with the humanist revival with its great emphasis on literary form. The classics now became the staple of education and classical philosophy and philology the occupation of the acuter intellects. Science was still neglected and often the cultivation of a good Ciceronian style became the sole aim of the scholar. The rapid extension of geographical and astronomical knowledge as well as the revival of the science of antiquity had surprisingly little effect on the educational scheme.

Even among the great humanists an interest in physical science was seldom in evidence and renaissance of science came later than that of the arts and of letters. The scientific spirit so far as it exists, is to be sought not among the acknowledged philosophers and scholars, but in the work of artists and obscure workers who were bold enough to break from tradition and to seek fresh paths. It was during the troubled years of persecution that followed the Reformation that the new spirit of science appeared in academic circles. The birth year of academic science was 1543, the year which saw the publication of the *De Revolutionibus Orbium Celestium*

of Copernicus (1473—1543) and the *De Fabrica Corporis Humani* of Vesalius (1514—1564). These works mark respectively the end of the long reign of Ptolemy and of Galen.

The work of Copernicus, though still hampered by preconceptions derived from the Greek tradition, was nevertheless the prelude to the modern period of astronomical research.[1] The heliocentric system of Copernicus offered a simpler means of interpreting the facts of observation and so prepared the way for the labours of Kepler, of Galileo and of Newton. The hostile attitude of the Church towards the new spirit of enquiry resulted in the martyrdom of Bruno and the persecution of Galileo. England was culturally far behind Italy, but in its freer atmosphere the new spirit flourished and men of science, though occasionally regarded with suspicion, were at least tolerated and some even enjoyed royal patronage.

The renaissance of science is marked by a tendency to turn from *a priori* or purely deductive method, toward the use of observation and experiment. The new attitude toward natural phenomena necessitated at the same time a definite restriction of the field of enquiry as is well exemplified in the works of Gilbert[2] (1543—1603) and of Harvey[3] (1578—1657). These two great investigators set themselves well defined and limited tasks. Gilbert, shaking himself free from the idle tales and trumpery of past generations, proceeded to investigate experimentally the properties of magnets and of the magnetic nature of

[1] D. Stimson, *The gradual acceptance of the Copernican Theory of the Universe.* New York, 1917.
[2] Wm. Gilbert. *De Magnete*, 1600.
[3] Wm. Harvey. *Exercitatio anatomica de motu cordis et sanguinis*, Frankfurt, 1628.

the earth. Harvey, though still steeped in Aristotelian philosophy, sets out on a definite line of enquiry, the *mechanical* explanation of the movement of the heart. He limits the scope of his search and refuses to discuss side issues, however attractive they may seem. This self imposed limitation is a mark of the modern scientific spirit which, in England, thus reached the self-conscious stage during the early years of the 17th century.

4. *Francis Bacon—the first philosopher of Science*

The method of experiment and of inductive enquiry was forced upon the notice of the world at large by Francis Bacon (1561—1626). He was not himself an effective scientific worker. Nevertheless, taking all knowledge to be his province, he drew up a complete scheme for scientific research. Now history shows that there is no *one* method common to all scientific discoveries and that except perhaps in the purely descriptive sciences such as natural history, discoveries are never made according to the pattern laid down by the Lord Chancellor. Scientific method consists in the framing of generalizations or laws and the description of observed phenomena in terms of certain concepts. But there is no single *method of discovery* as Bacon would have us believe. The whole question of scientific method, however, has such an important bearing on the teaching of science and so much controversy has raged round the possibility of teaching scientific method in schools that we shall have to consider the problem again at a later stage.

A novel feature of Bacon's scheme was the claim that acuteness and strength of wit are not necessary in the search for truth. What a comforting conclusion! All

the student has to do is to follow the method—he will then succeed, Bacon tells us, just as an unpractised draughtsman can draw a straight line if provided with a good ruler! The student must begin with an open mind, keeping clear of the various *idola* and proceed to collect facts and "all the known instances" as "a mere history and without any premature reflection." Bacon gives an example of the application of his infallible method over the investigation of the *form of heat*.[1] He makes a "table of existence or presence" consisting of some twenty-eight instances in which heat is produced. He then proceeds to balance these affirmatives with certain negatives and after a long discussion concludes that "heat is an expansive motion restrained, and striving to exert itself in the smaller particles."

Bacon's arguments appear so plausible on the surface that we can understand how the facile optimists of his day became drawn towards his pansophic ideal. But we must remember that scientific discoveries do not come about according to set rules of thought. The man of science does not keep an entirely open mind. His experiments are often but the means of verifying a hypothesis already conceived. Again, in the case of the so-called accidental discoveries we find that the final synthesis could only have been made by a mind already familiar with the relevant facts. As Lagrange once said, "accidents only happen to those who deserve them." The objection to Bacon's teaching is that scientific discovery is made to appear too easy. Now what he describes is not the process of discovery, but the verification or demonstration carried out by some onlooker

[1] *Novum Organum*, 1620. English Edition by Pickering. London, 1844, p. 132 *et seq.*

when the hard work has been done. Proof presupposes knowledge. It is easy enough for the philosopher to point out how a new truth follows from an old truth. Bacon's student of slow wit can readily see the connection between the steps of such reasoning. How easy is it then. But Bacon's short-cut to truth stands self-condemned by the very phrase "all the facts and known instances." There is no fact without a perceiving mind, and what is observed depends on the mental content and attitude of the enquirer. Scientific discovery involves an act of judgment and the choice of the facts observed depends upon the knowledge the observer has at his disposal. How then can "all the facts" be observed? Bacon, we must remember, was woefully ignorant of contemporary advance, and he makes frequent gibes at Gilbert for "probing at a solitary matter." Gilbert, like other investigators, pursued his work and reached his end in his own way. Yet the teachings of Bacon caught the popular fancy. His proposal for a palace of invention where research would be so systematized that there would soon be nothing new to discover, was a particular pleasing one.

It is easy for us now to criticize Bacon, but we must recognize the important place he occupies in the study of our subject. He was, in fact, the first modern philosopher of science and the first popularizer. The fact that he was a man of letters and not an investigator enabled him to view the labours of the man of science from the outside. His works were widely read, especially the *Advancement of Learning*, which went through eleven editions before the middle of the century. His survey of existing knowledge given in this work together with the powerful appeal for the recognition of the supreme worth

of intellectual pursuits had an undoubted influence on education and particularly on education in science.

5. *Some 17th Century Influences*

René Descartes (1596—1650) was the first philosopher of modern times to formulate an effective unitary theory of the universe. He had a deeper insight into the significance of the problem of knowledge than Bacon. His influence on scientific thought was far more profound.

Descartes tells us in his *Discourse on Method* (1637) that he resolved :

1. "Never to accept anything for true which he did not clearly know to be such : that is to say, carefully to avoid precipitancy and prejudice. . . ."
2. "To divide each of the difficulties under examination into as many parts as possible."
3. "To conduct his thoughts in such order that, by commencing with objects the simplest and easiest to know, he might ascend to the knowledge of the more complex."
4. "To make enumerations so complete and reviews so general that he might be assured that nothing was omitted."

Thus the first step in the method of Descartes is *Doubt*. He recognized no authority from without and maintained that the mind is free to seek its own conclusions. His reasoning was based on the certainty of the subjective life. *I think, therefore I am.* This, to him, was an obvious certainty and hence true. Similarly the conception of the soul as separate from the body was also obvious and hence true. The dualism of the body-mind relationship and also that of the inner and

outer worlds determined to a large extent the subsequent course of philosophy.

The criterion of truth accorded to Descartes is the existence of clear and distinct ideas. He claims that the experiences and judgments of the individual mind form a sufficient basis for an interpretation of the world around. In the *Discourse on Method* Descartes speaks in the first person and deduces all his arguments from his own reflections. The emphasis of Descartes on the sufficiency of the human reason marks the beginning of what is usually regarded as modern philosophy.

Descartes sought to include all the external phenomena of the universe in a simple mechanical system. He admitted none of the occult qualities beloved of the schoolmen and granted only two properties to matter *extension* and *motion*. He endeavoured to reduce all mechanics and physics to a geometry of motion. For Descartes exact knowledge is essentially mathematical and he aims at expressing comparisons as numerical ratios. Weight and velocity he conceives as dimensions of motion, while length, breadth and depth are dimensions of extension. Although Descartes did not expound a conception of mass, yet he realized that moving bodies have a measurable efficacy. This led him to assert that the *quantity of motion* in the universe remains constant.

In his *Principia Philosophiæ* (1644), Descartes develops his famous theory of *vortices*. He denies the existence of indivisible portions of matter (atoms) and denies also the possibility of a vacuum. He conceives the universe completely filled with extended substance originally set in motion by God. In this tightly packed universe the movement of any one portion of matter will affect adjacent portions. The *primary matter* of Descartes is

conceived by him as forming whirlpools or vortices from the motion given to it by God in the beginning. Objects in contact with this primary matter are, therefore, carried round in these vortices. The earth and other planets he conceives as carried round in a great vortex with the sun as centre. He thus admits the essence of the Copernican system but cautiously refrains from expressing formal support.

The investigations of Descartes in mathematics, physiology and experimental physics do not concern us here. But his philosophy, though worded with skilful ambiguity for fear of giving offence to the Church, pictured a universe wholly explicable in terms of motion and extension in which everything happens with the regularity of a well lubricated machine. Here was something vastly different from the teleological and spiritual conception of the universe which had held the field for so long. In the Cartesian system there was no need for constant Divine intervention in the affairs of the universe. The machine once wound up, went on of its own accord.

Contemporary with Descartes was Pierre Gassendi (1596–1650) the Epicurean philosopher who succeeded in remaining a good Catholic all his life. Gassendi was a zealous student of the physical sciences and upheld the theory of atoms. Descartes and Gassendi were prominent members of that brilliant scientific circle which centred round Mersenne in Paris. It was into this group of philosophers that the English thinker Hobbes (1588–1679) was introduced when on a visit to France. The intimacy between Hobbes and Mersenne lasted for many years and Hobbes was called upon by Mersenne to criticise the *Meditations* of Descartes. In spite of the

extreme individualism of Hobbes there were sufficient points of resemblance between his mechanical system and that of Descartes to render a modified Cartesianism acceptable to the adherents of Hobbes and equally detested by his enemies.

The first direct attempt to introduce Cartesianism into England, however, was made by Antoine Le Grand. His vast treatise, *An Entire Body of Philosophy according to the Principles of the famous Renate des Cartes* appeared in 1682 and an English translation in 1694. The Cartesian philosophy was officially rejected at Oxford, and Samuel Parker (1640–1688), Bishop of Oxford, made bitter attacks on Gassendi, Hobbes, and Descartes. The new philosophy, however, found a temporary home at Cambridge where it was welcomed with some reservations by the neo-Platonists led by Cudworth (1617–1688) and More (1614–1687). The physics of Descartes was familiar at Cambridge and was often studied in Latin and English translations of the *Traité de Physique* of Jacques Rohault. Cartesian geometry, we are told, first attracted Newton to the study of mathematics.

One of the few examples of unstinted approbation of Descartes in English is to be found in Joseph Glanvill's *Scepsis Scientifica or Confest Ignorance the Way to Science* (1655). Glanvill's own contributions to philosophy are unimportant but his writings are of interest as appearing during the early formative years of the *Royal Society*, One of the reasons why Cartesianism did not flourish long in English soil may have been that the most active independent minds such as Boyle, Hooke, Mayow, Wren, were far more interested in experimentation than in argument. Indeed Boyle while acknowledging Bacon, Descartes and Gassendi as his leaders, tells us that he did

not read them seriously that he "might not be prepossessed with any theory or principles" before he had time to try things for himself. Moreover, though the air resounded with the preaching of Bacon on the experimental method, certain English thinkers of the time were influenced to a greater extent by Galileo (1564–1642) than by either Bacon or Descartes.

In the year that Galileo died, Newton was born. The vast achievements of Galileo were carried to a triumphant completion by Newton. While the world waited for the flowering of Newton's genius the work of Galileo was already leavening English thought. Throughout the writings of Hobbes, for example, we find abundant evidence of his direct indebtedness to Galileo. The distinction between *primary qualities* and *secondary qualities* which goes back to Democritus was set forth clearly in Galileo's *Il Saggiatore* (1624). The discussion reappears not only in the writings of Descartes and Gassendi but in the works of Hobbes,[1] Boyle,[2] and Locke.[3] The *primary qualities* of a body, according to Galileo, are its boundaries, shape, size, hardness, etc., its *secondary qualities* are our perceptions of its colour, taste, smell and our sensations of heat and cold. Galileo held that in a universe in which there were no ears, tongues, noses or other organs of sense, the primary qualities of shape, quantity and motion would yet remain. Such a universe was the one explored by Galileo, by Newton and their followers. Such was the realm of extension and motion of Descartes and of the "external objects" of Locke.

[1] T. Hobbes, *Leviathan*. 1651.
[2] R. Boyle, *The Origine of Forms and Qualities*. 1666.
[3] J. Locke, *An Essay Concerning Human Understanding*. 1690.

The physical system of Descartes threatened by that of Galileo was finally overthrown by Newton. The *Principia* of Newton was published in 1687. Within the next few years David Gregory (1661–1708) gave public lectures on the Newtonian philosophy in Edinburgh. Gregory became Savilian Professor at Oxford in 1691 and inspired John Keill (1671–1721) and William Whiston (1667–1752) with enthusiasm for the new philosophy. Keill and Whiston were among the first to popularize the Newtonian physics. Whiston gave lectures at Cambridge to bring "that Divine philosophy within the reach and comprehension of those who are but indifferently exercised in mathematics." These lectures were afterwards published.[1] He was one of the first to give experimental lectures in London.[2] Perhaps the first text book expounding the Newtonian principle of gravitation was Gregory's *Astronomiæ Physicæ et Geometricæ Elementa*, published at Oxford in 1702 with the approbation of Newton himself. In 1716 there appeared an English translation of Rohault's treatise, "the Cartesian errors being corrected upon the Newtonian system." An investigation of science teaching during the early decades of the 18th century reveals that the physical system of Descartes once displaced by that of Newton, was never resuscitated though the tradition of metaphysical thought of Descartes acting through Locke and the empirical school led on to later philosophical developments.

[1] W. Whiston, *Sir Isaac Newton's Philosophy more easily explained.* London, 1716.

[2] W. Whiston and F. Hauksbee, *A Course of Mechanical, Optical, Hydrostatical and Pneumatical Experiments.* London, probably 1730.

Chapter II

The Rise of the Academies

6. *A Growing Interest in Education*

THE first work of English origin devoted exclusively to education is that of Thomas Elyot (1499?—1546) who describes what he conceives to be the ideal upbringing of a gentleman.[1] In addition to a training in military exercises, he recommends that the youth shall study modern maps, geometry and astronomy. He has nothing to tell us about the actual method of instruction.

A plan for an academy was put forward in 1570 by Humphry Gilbert [2] (1539?—1583), who proposed a wide curriculum including natural philosophy and physic. Such schemes were doubtless encouraged by the fact that at the time and throughout the reign of Elizabeth the number of students at Oxford and Cambridge was increasing, and the colleges becoming very wealthy. Leading citizens were beginning to take an interest in education. Both the University of Edinburgh and Trinity College, Dublin, were founded at this time through the influence of men of affairs.

In 1565 Sir Thomas Gresham (1519?—1579), a London merchant, bequeathed to the aldermen of the city the rents arising from the shops he owned over the Royal

[1] Sir Thomas Elyot, *The Boke named the Governor.* 1531.
[2] Sir Humphry Gilbert, *Queene Elizabethe's Achademy.* Early English Text Society, 1869.

Exchange and the sum realized by the sale of his residence in Bishopsgate Street. The money was to be devoted to the erection of a College in which seven professors should give lectures in astronomy, geometry, physic, law, divinity, rhetoric and music respectively, one subject being assigned to each day of the week. The scheme materialized in 1597 and Gresham College became a miniature university.[1] The college buildings in Bishopsgate Street contained an observatory and residential quarters for the professors. By Gresham's will the appointment of the staff was in the hands of the Mayor and Corporation of the City of London. The first professor of Geometry was Henry Briggs (1561—1631). Isaac Barrow (1630—1677) was professor of Astronomy at the College before he became Lucasian Professor at Cambridge (see p. 38). Robert Hooke (1635—1703) was Professor of Geometry at Gresham College for a time. Lectures were given at the college until 1768 after which the site was rented by the Crown.

7. *The Followers of Bacon*

That Bacon's views produced an effect on contemporary writers is shown by the flood of literature in the middle 17th century bearing on the advancement of learning, the very titles showing the source of their inspiration. Thus in 1640 HezekiahWoodward (1590—1675) referred to Bacon as "our great Advancer of Learning." Seven years later Sir William Petty (1623—1687) wrote a tract on education with the title *Advice of*

[1] George Buck, *The Third Universitie of England*, London, 1613.

William Petty for the Advancement of some particular parts of learning. In 1649 John Durie (1596—1680) wrote on *An Agency for the Advancement of Universal Learning*, and in 1661 appeared the *Propositions for the Advancement of Experimental Philosophy* of Abraham Cowley (1618—1667). The Baconian encyclopædic ideal and the insistence on a study of nature is evident in all these works.

The greatest of Bacon's disciples, however, was Jon Amos Komensky, who name is better known in its Latinized form of Comenius (1590—1670) one of the most earnest yet most exasperating optimists who ever lived. For him as for Helvetius, *l'éducation peut tout.* The *Great Didactic*[1] of Comenius is a treatise "setting forth the whole art of Teaching all Things to All Men, or a certain inducement to found such schools in all the parishes, towns and villages of every Christian kingdom, that the entire youth of both sexes, none being excepted, shall quickly, pleasantly and thoroughly become *learned in the sciences*, pure in morals, trained to piety, and in this manner instructed in all things necessary for the present and for the future life."

Samuel Hartlib (d. 1670), a citizen of the world and an interesting figure in 17th century science, when a student on the continent came under the influence of Comenius and so became enthusiastic for the better welfare of mankind. It was through Hartlib that Comenius was persuaded to leave his native Moravia and to visit England. The joint plans of the two men for the reorganization of education and for the establishment of a college on Baconian lines came to naught owing to the

[1] *Didactica Magna*, 1630. Translated into English by M. W. Keatinge, Oxford, 1896.

outbreak of the civil war. The government had regarded the scheme favourably and, indeed, educational reform was in the air, for there were already plans on foot for the establishment of a University of London. But all such schemes had to be set aside. Hartlib, however, was not to be outdone. He approached Milton on the subject of educational reform, and so drew from him the Tractate *Of Education* (1644) in which he, too, outlined a plan for an academy which should give a wide education to all. As we should expect, Milton proposed that the scientific part of the instruction should be derived from the classical writers. Indeed, the *Tractate* is of no importance in the history of science teaching.

8. *The Royal Society*

The elaborate plans for a great academy had to be abandoned when England was divided against itself. But during that time of turmoil and bloodshed small groups of men, drawn together by a common love for science, held meetings for the discussion of philosophical problems, and thus formed the nucleus of the Royal Society.

An account of the beginning of the Royal Society and the early informal discussions is contained in a tract written by John Wallis (1616—1703), one of the original fellows [1]:

> " I take its first ground and foundation to have been in London about the year 1645 (if not sooner) when

[1] *A Defence of the Royal Society and the Philosophical Transactions particularly those of July*, 1670, by John Wallis, D.D., Professor of Geometry in Oxford and Fellow of the Royal Society, London, 1678.

> the same Dr. Wilkins (then Chaplain to the Prince Elector Palatine in London), Dr. Jonathan Goddard . . . with myself and some others met weekly . . . where (to avoid diversion to other discourses and for some other reasons) we barred all discourses of Divinity, of State-affairs and of News (other than what concerned our business of Philosophy), confining ourselves to Philosophical Inquiries and such as related thereunto as Physick, Anatomy, Geometry, Astronomy, Navigation, Mechanics and Natural Experiments. We there discovered the circulation of the Blood, the Valves in the Veins, the Copernican Hypothesis, the Nature of Comets and new Stars . . . the Improvement of Telescopes and grinding of Glasses for that purpose (wherein Dr. Goddard was particularly ingaged and did maintain an operator in his house for that purpose) the weight of Air, the Possibility or Impossibility of Vacuities and Nature's abhorrence thereof, the Torricellian Experiment in Quicksilver, the Descent of Heavy Bodies, and the Degrees of Acceleration therein, with others of a like nature. Some of which were then but new Discoveries, and others not so generally known and embraced as now they are."

The meetings were first held, so Wallis tells us, at Dr. Goddard's house in Cheapside and in the Mitre Tavern near by in Wood Street. Later they met at the Bull Head Tavern, and, during term time, at Gresham College. Robert Boyle (1627–1691) joined the club as the youngest member a year after the foundation. William Petty, who was introduced by Hartlib was

another keen young member. But the Philosophical College, or *Invisible College*, as Boyle called it, was soon to lose some of its most prominent members. One of the first acts of Parliament in the early days of the Commonwealth was the "purgation" of the universities. Certain heads were deposed and safer men appointed in their stead. In this way Wallis, Goddard, Wilkins and Petty went to Oxford. They soon gathered kindred spirits around them and a branch of the Invisible College was formed. They met for some years at Petty's lodgings and later at Wadham College. In 1654 Boyle and his assistant Robert Hooke (1635—1703) began experimental investigations at Oxford, and soon Christopher Wren (1632—1723) began to attend the meetings. When in 1657 Wren became professor of Astronomy at Gresham College, members used to travel to London to hear his weekly lectures. The London and Oxford branches continued with some interruptions until the Restoration.

On November 28th, 1660, an important gathering took place at Gresham College after one of Wren's lectures. The establishment of a college for promoting "Physico-Mathematical Experimental Learning" was discussed and a set of rules drawn up. At a later meeting the members signed a declaration to meet weekly when possible and to pay 1s. per week towards necessary expenses. It then seemed desirable that the society should rest on a more formal basis and a petition for incorporation was sent to Charles II. On July 15th, 1662, the Charter was given, the humble club which "met weekly to consult and debate concerning the promoting of experimental learning" becoming thereby elevated to the Royal Society, the King proclaiming himself the Founder.

9. *The Spread of Scientific Knowledge*

With the establishment of the Royal Society we reach a landmark in the history of science. The meetings of the Fellows brought together investigators in various fields, and although the subjects of some of the early discussions seem trivial and show evidence of boundless credulity, yet the interchange of ideas was in itself valuable for the progress of science. The Royal Society supported a research laboratory at Gresham College where certain experiments suggested by the Fellows were carried out. Hooke was the first curator and Papin was appointed shortly afterwards to serve jointly with Hooke. Evelyn describes, with his relish for detail, how Papin entertained the Fellows to supper where they sampled a dish prepared by means of Papin's famous digester!

The *Philosophical Transactions* appeared for the first time in 1665. The publication was due to the initiative of the Secretary, Oldenburg, who bore the expenses in the first instance. The sale of the volumes to the Fellows and to the general public soon resulted in a good profit, and the circulation of the Transactions was of great importance for science in England and abroad. The official foreign correspondence, well organized by the indefatigable Oldenburg, constituted what we might call the publicity work of the new society. Distinguished men from the continent were made Fellows, as Huygens in 1663, and Malpighi, Leibniz and Leeuwenhoek shortly afterwards. Works published directly by the Royal Society, or through the influence of individual fellows, give evidence of the great activity during the

twenty years following its incorporation. Among them were:

1665	Hooke, *Micrographia.*
1669	Malpighi, *Anatomy of Plants.*
1676	Evelyn, *Philosophical Discourses on the Earth.*
1686–88	Ray, *Historia Plantarum.*
1687	Flamsteed, *Tide Table.*
1686–87	Newton, *Principia.*

The work of Galileo was known in England at least as early as 1648, and is mentioned in a book on mechanics by John Wilkins published in that year, *Mathematical Magick or The Wonders that may be performed by Mechanical Geometry.* Galileo, as the founder of the science of dynamics prepared the way for Newton, whose vast creative work not only provided a systematization and simplification of scientific knowledge, but influenced profoundly the whole of European thought. The seventeenth century also gave us the work of Harvey (see p. 8), Malpighi (1628—1694), Leeuwenhoek (1632—1723), and Ray (1627—1705) in Biology. In Chemistry there was the transition from alchemy to chemistry marked by the work of Mayow (1640–1679) and of Boyle.

An interesting contemporary view of 17th century science is given in a little work by Joseph Glanvill (1636—1680) published in 1668. *Plus Ultra or the Progress and Advancement of Knowledge since the days of Aristotle—in an account of some of the most remarkable late Improvements of Practical and Useful Learning.*

We learn that at this time the Cartesian philosophy was well known in England, Glanvill describing Descartes

as "one of the greatest wits that ever the sun saw, a person too great for praise, designed by Heaven for the instruction of the learned world." Glanvill mentions the use of logarithms discovered by Napier of Merchiston (1550—1617) and the wonders revealed by the microscope and telescope, and exalts the experimental method as the only means of reliable enquiry. He explains that the three great means for the spreading of knowledge are (1) Printing, (2) the Compass, (3) the Royal Society. He tells us that the Royal Society have done "more than all the philosophers of the Notional way since Aristotle opened his shop in Greece . . . whoever compares the Repository of this society with all the volumes of Disputers will find (this statement) neither immodest nor unjust." Glanvill's claims are not extravagant for there was an entire change of outlook during the 17th century which marks it as the century of science.

During the period we have been considering various scientific academies were established on the continent. As early as 1603 there was founded in Italy the Academy of the Lynx of which Galileo was a prominent member. This society declined, but from the ashes arose the famous Accademia del Cimento (1667). In 1664 an academy was founded at Nürnberg. Leibniz became a member and afterwards Secretary. In France, men of learning banded themselves into a secret society to discuss questions of philosophy. From this small beginning arose the Academy of Sciences which was formally established in 1666.

Chapter III

The Beginnings of Science Teaching in Universities and Schools

10. *Conservatism of Universities and Grammar Schools*

FROM the 13th to 16th centuries university students were of what we should now regard as school age. During this period, therefore, school and university teaching may be considered as one for our purposes. The curriculum, as we have seen, consisted of the seven Liberal Arts. The chief subject of instruction in the more advanced schools was grammar, and consequently the term *grammar school* came into use. The subjects of the *quadrivium* provided what we might call the scientific side of the instruction, but the content was meagre and Aristotelianism persisted in the universities long after the modern scientific attitude had shown itself in the greater world outside. We find in the Oxford Statutes of 1431 that the requirements for the B.A. degree include two terms' work on one of the following works of Aristotle: The *Physica*, *De Coelo et Mundo*, *De Plantis*, *De Anima*, *De Animalibus*.[1] Two hundred years later the same topics are still being studied at Oxford and in 1636, the Laudian Statutes prescribed that the Sedleian Lecturer in Natural Philosophy should

[1] Hastings Rashdall, *Universities of Europe in the Middle Ages*, Oxford, 1895.

expound the same works. Mathematics, however, was held in esteem at the universities from the beginning.[1] Natural Science, as we should understand the term, did not enjoy an established position until the second half of the 19th century.

Now all teaching must to some extent lag behind advancing knowledge. It is not until new results have become absorbed into the body of knowledge that they are handed on to the student generation. Mathematics was already in a relatively advanced stage in the early 17th century, and the Cartesian geometry was taught at Cambridge when Newton was an undergraduate. The Royal Society did much to spread an interest in scientific studies among the general public. But the infiltration of the Universities by the Newtonian philosophy was a slow process. Apart from what we may call the "natural lag," the close association between the church and university tended to keep out the newer studies. Thomas Sprat (1635—1713), that versatile divine, found it necessary to emphasize that the new experimental method would be in no way harmful to the Christian religion, and he assures his readers that it "would not injure education." He tells us in a very enlightening passage: "The art of experiments is not thrust into the hands of boys or set up to be performed by beginners in the school, but in an assembly of ripe years. . . . They still leave to learners and children the old talkative arts which best fit the younger age. From this it must follow that the various manners of education will remain undisturbed."[2]

[1] Roger Bacon, for example, claimed that Oxford was the first mathematical school in Europe.

[2] Thomas Sprat. *The History of the Institution, Design and Progress of the Royal Society of London*, London, 1678, p. 345.

If Sprat merely echoed the views of his contemporaries we can well understand the difficulties that beset those who proposed to introduce experimental work into the schools. We find that the curriculum of the grammar schools of old foundations remained predominantly classical until the 19th century. The reason was largely due to the statutes of the founders who had prescribed the course of study. The very antiquity of the old grammar schools, from which our nine great public schools were derived, explains the rigidity of the tradition.

11. *Science Teaching Outside the Schools*

While the curriculum of the grammar schools was controlled by authority, and that of the "petty" schools limited to the barest rudiments of instruction, the education of a nobleman and of the sons of the wealthy was wide in content and outlook. During the 17th century especially there arose a type of English country gentleman, scholarly to some extent, interested in natural science and in outdoor pursuits. The founders of the Royal Society were, on the whole, men of means and leisure. It is interesting to note that Peacham in his *Compleat Gentleman* of 1662, includes cosmography and geography, in his suggested curriculum for the education of a gentleman, and when explaining the educational value of the grand tour recommends that chemistry and physic be learned *en route*. In Milton's *Tractate* (see p. 21) also, we find natural history, medicine, and anatomy included as part of the subjects for a gentleman's study. Some knowledge of "physic" or medicine

was often sought by those who had no intention of ever practising as physicians. Since the study of herbs and plants was always closely associated with the study of medicine, we find botany also included in the curriculum. Herbert of Cherbury (1583—1643) says, "It is a fine study and worthy of a gentleman to be a good botanic so that he may know the nature of all herbs and plants,"[1] and Burton (1578—1648)[2] expresses the same view. These are but pious expressions of opinion and have not much relation to the actual educational practice of the day. Many schoolmasters, during the 17th century, were, however, practising physicians, and this probably accounts for the introduction of natural history teaching into the schools.[3]

12. *Comenius and Sense Realism*

The reaction against the meticulous study of grammar and literary form which characterized the last stages of humanism led to a plea for sense realism which involved training through the senses. Such a training had been advocated by such writers as Erasmus and Vives, the Spanish humanist and educational reformer, but it was Francis Bacon who inspired the great movement for sense realism during the 17th century. Bacon's teaching was applied to pedagogy by Comenius. Beginning with the statement imputed to Aristotle, *Nihil est in intellectu*

[1] Herbert, *Autobiography*.
[2] Burton, *Anatomy of Melancholy*, 1621.
[3] Philemon Holland, translator of Pliny's *Natural History*, was a doctor of medicine, and appointed headmaster of the Grammar School at Coventry in 1628.

quod non primus fuit in sensu,[1] Comenius proceeded to elaborate a scheme for teaching young children by means of objects and pictures. The textbook of Comenius[2] is a profusely illustrated Latin reader describing birds, animals, plants and everyday occupations. There are diagrams showing the phases of the moon, and the formation of eclipses. Moral teaching is introduced also by means of pictures. Thus we are shown a man standing with a rather mild angel on his left and an energetic devil on his right, the eye of Providence looking down through a break in the clouds. Not only did Comenius advocate the use of pictures but he makes a plea for experimental teaching also. "Is there a man," he asks, "who teaches Physics by observation and experiment and not by reading an Aristotelian or other text book? . . . Men must be instructed in wisdom as far as possible, not from books but from the heavens, the earth, the oak and the beeches. That is, they must learn and investigate the things themselves and not merely the observations and testimonies of other people."

Although Comenius' sojourn in England was brief, his views were made known by his friend Hartlib. Comenius proposed that science teaching should be introduced into the schools, physics and mathematics together with grammar, rhetoric and dialectic forming the curriculum of the Latin school for pupils of ages 12—18. As a means of introducing science teaching without tears, Comenius wrote a school play which was published in England in 1664. As a performance, it

[1] This phrase is not in fact to be found anywhere in the actual writings of Aristotle. The humanist writers took it, however, from the current Latin translation of the commentary by Averroes of Aristotle's *Metaphysica.*

[2] *Orbis Sensualium Pictus.* Translated by Charles Hoole, Teacher of a Private Grammar School in Lothbury. London, 1658.

must have been dismal in the extreme, for it consists of lengthy descriptions of the natural products of the earth and the showing of specimens to the audience during the recital by the performers. The naïve admixture of moral teaching and science, characteristic of the writings of Comenius, is well seen in the English translation of his work on physics, published in London, 1651, with the title: "*Natural Philosophie Reformed by Divine Light: Or a Synopsis of Physics by J. A. Comenius: Exposed to the Censure of those that are Lovers of Learning and desire to be taught by God. Being a view of the World in Generall, and of the particular Creatures therein contained: grounded upon Scripture Principles with a briefe Appendix touching the Diseases of the Body, Mind and Soul.*"

A further plea for simplified science teaching in the vernacular was made by one George Snell. His work *On the Right Teaching of Useful Knowledge*, which appeared in 1649, was dedicated to Durie and Hartlib, and is written in the Comenius vein. Snell outlines a scheme for the teaching of "good manners, logic, cosmography, geography and natural philosophy." The following extracts from his chapter on *Cosmographie* show that he did not consider it at all necessary to acquaint the young mind with the Copernican system even in the year of Grace 1649!

> ". . . That the universal bodie of the world is of a round figure of which the utmost circumference is on everie point equidistant from the center, heart, and inmost part of the earth . . . which by the omnipotent decree of the Almightie, lieth

immovable in the midst of the Element which we call air, which air doth compass round both sea and land. . . . The highest orb is immovable, to wit, the heaven of glorie the state-mansion of Angels: and the lowest, to wit, the earth, is likewise immovable: as the two boundaries limiting the large field of created substance."

An English pioneer of nature study and training through the senses was Hezekiah Woodward (1590—1675). The title of his book published in 1641 certainly raises the hopes of the reader: *A Gate to the Sciences opened by a Naturall Key or a practical Lecture on the great Book of Nature, whereby the Child is enabled to read the Creatures there.* He urged that by science teaching, the pupil could become " a free denizen of the world." He realizes that pictures must in many cases take the place of the actual object. " I know no better way," he says, " than by emblems . . . for pictures are the most intelligible books that children can look upon." Again he says " Nothing comes into the understanding in a natural way but through the senses. . . . Make the child not a hearer only but a party in the business. . . . Speaking wholly (by the parent or teacher) is lost labour."[1] Woodward was himself a schoolmaster in London, so that there is every reason to believe that in his school, at least, the children received something more than book learning.

The great cry of the advocates of sense realism was " things not words "—and imbued as they all were with the Baconian philosophy they thought that here was a

[1] *Of a Child's Portion.* London, 1640.

pedagogical method that would transform the whole of education. Such views certainly were expressed by Hartlib, Durie,[1] Evelyn, Cowley and Petty. The value of handwork as a means of education was strongly advised by Petty in a work entitled: *Advice to Mr. Samuel Hartlib on the Advancement of Some Particular Points of Learning.* London, 1647. Petty even advised that children of all classes should be taught some "genteel manufacture," and also learn the history of the various trades. He believes that since children delight in "things" that they can see and handle they will learn pleasurably and not have to be driven to their tasks. He affirms, too, that such an education is natural and suited to the developing propensities of the child. Many passages in this work remind us of the later writings of Locke, Rousseau and Pestalozzi.

13. *Natural History Teaching during the Seventeenth Century*

Since educational practice rarely coincides with the recommendations of the reformers it will be well for us to consider the actual content of science teaching at this time. Of natural history teaching at the universities we know little. At Oxford, the first Professor of Botany, Robert Morrison, was appointed in 1669. There was no similar appointment made at Cambridge. He is said to have "translated himself to the Physic Garden, where he read . . . on herbs and plants twice a week

[1] J. Durie, *A Motion Tending to the Public Good of this Age and of Posterity.* London, 1642.

for five weeks space.[1]" His lectures attracted attention in Oxford and his work *Plantarum Oxoniensis* was an important contribution to the subject.[2] Nevertheless, the work of Morrison and of his more illustrious contemporaries, Boyle, Hooke, Mayow, Lower (1631—1691) and Willis (1621—1675) did not leave its mark on the official university teaching. Students who wanted instruction in the newer developments of science had to depend on private teachers.

A curious indication of the public recognition of scientific discoveries at this period is to be found in the *Musæ Anglicanæ*. This is a collection of what we might call "prize poems" of the 17th century. Among the current topics which attracted sufficient attention to be enshrined in the dignity of Latin verse we find such subjects as the Microscope, Pneumatic Machines, the Spheres and the anatomical investigations of Thomas Willis. It is surprising how much of the attention of these academic poets is concentrated on Science.

Some interesting facts about the actual teaching in schools are given by Charles Hoole (1610—1667) in his *New Discovery of the Old Art of Teaching School* (1660). In his school the boys read Pliny's *Natural History* and the *Bucolica* of Virgil. He encouraged his pupils to take an interest in natural objects such as those found in museums. He says "London, of all places I know in England, is best for the full improvement of children in their education. because of the variety of objects which daily present themselves to them, or may easily be seen . . . by walking to Mr. John Tradescant's or the like

[1] E. C. Mallett, *History of the University of Oxford.* London, 1924 and Vines & Druce. *The Morisonian Herbarium.* Oxford, 1914.

[2] An account of the Physic Garden is given in *Collectania* IV, p. 187.

houses or gardens where rarities are kept." This museum was the origin of the Ashmolean.

Of the 17th century works on zoology we may mention the *Speculum Mundi* of John Swan, which appeared in 1635. The book combines the absurd traditions of the *Physiologus* with the Biblical account of the creation of the Cosmos. This work seems to have been a favourite among the more pious schoolmasters of the day. Another school textbook was the *Zodiacus Vitæ*. This was a mixture of fabulous tales, moral teaching, and scraps of natural history, the whole written with a strong Protestant bias and frequent invectives against the Church of Rome. Hoole himself wrote an easy natural history book: *A Plain and Easy Primer for Children wherein the Pictures of Beasts and Birds for each letter of the Alphabet are set down.* This was prefixed to his translation of the *Orbis Pictus.* Although the systematization of zoology and botany was hardly begun until the time of John Ray (1628—1705) and was really the work of the 18th and 19th centuries, yet the great number of works on natural history appearing in the catalogue of a shrewd bookseller of the time [1] show that there must have been a widespread interest in those subjects many years before.

14. *The Teaching of Physical Sciences during the Seventeenth Century*

Towards the end of the 17th century there was a sufficient body of knowledge in chemistry, physics and

[1] Wm. London, *Catalogue of the Most Vendible Books in England.* 1658.

the mathematical sciences to warrant definite teaching at the universities. Officially these institutions remained Aristotelian and successful disputation still gave a claim to academic distinction. But outside the actual university organization, private teachers gave instruction in the newer studies. John Wallis tells us that at Oxford there was teaching in physics, chemistry, anatomy, botany and modern languages. "I do not know any part of useful knowledge proper for scholars to learn, but that if any number of persons, gentlemen or others, desire therein to be informed, they may find those in the university who will be ready to instruct them."[1] One of these unofficial teachers of Oxford was Peter Sthael of Strasbourg who was introduced to Boyle through the influence of Hartlib. Sthael taught practical chemistry in a private house near University College from 1659 to 1664. Christopher Wren and John Locke were among his pupils.

The first chemical laboratory of university status was the outcome of the gift of Elias Ashmole (1617—1692). The museum of "rarities" belonging to Tradescant was conveyed by deed of gift to Ashmole who afterwards presented the whole collection to the University of Oxford.[2] Ashmole proposed the establishment of an academy in Oxford on the lines of Gresham College. But his scheme was shortlived. A building to house the collections was erected by the University and one of the

[1] John Wallis' letter written in 1700 in *Collectanea.* First Series Oxford Historical Society. Oxford, 1885.

The clear outlook characteristic of the genius of Wallis is well shown in his *Discourse on Gravity and Gravitation. Presented to the Royal Society, 12th November*, 1674.

[2] R. T. Gunther, *Early British Botanists and their Gardens*, Oxford, 1922.

rooms was fitted up as a chemical laboratory. We hear of the appointment of two Ashmolean professors of chemistry. But after the death of the founder the enthusiasm of Oxford seems to have waned and now the name of Ashmole is associated only with the archaeological collections of the University, housed in the Ashmolean Museum.

Of the University Professorships in the physical sciences established during the 17th century, we must note the following: At Oxford, the Sedleian Professorship of Natural Philosophy (1621) and the Savilian Professorship of Geometry (1619) and of Astronomy (1621). At Cambridge the only endowment in the physical sciences during this period was the Lucasian chair of Mathematics established in 1663.

There was no physical science teaching in the schools at this time in our present acceptation of the term. The grammar schools were limited by the statutes of the founders to a purely classical curriculum. But apart from this, school science teaching had to wait until the subjects were sufficiently systematized and until there were teachers available who knew enough of the fundamentals to expound them to their pupils. The study of any science presupposes a moderate knowledge of the instrumental subjects, and it was the main business of the schools to bring their pupils up to some standard of attainment in these studies.

Several elementary textbooks, however, were published in the 17th century.[1] Of these we may mention the *Mathematicall Magic* of Wilkins (1649) (see p. 25) and

[1] A full account of the introduction of modern studies into schools is given in Foster Watson: *Beginnings of the Teaching of Modern Subjects in England.* London, 1909.

the *Peripateticall Institutions* of Thomas White (1656) which was a descriptive book on physical geography and Aristotelian physics. Possibly individual schoolmasters attempted some training through the senses but we have no record of any general response in the schools to the appeal of Comenius and his disciples.

Chapter IV

Educational Precept and Practice in the Eighteenth Century

15. *Contemporary Views on Education*

THE works of Locke published during the last decade of the 17th century mark the beginning of a new era in the history of education. The psychological principles set forth in the *Essay Concerning Human Understanding* (1690) made a strong appeal to educational reformers. Locke's picture of the mind at birth as a *tabula rasa* on which the educator may write what he will was certainly flattering to the vanity of the teacher. Locke held that the " Fountains of knowledge whence all our ideas come " are sensation and reflection. The sensations depend on the observations and experiences of the individual. The reflection or subsequent reasoning was supposed to lead to the discovery of new truth. Locke ignored the endowment or *naturel* of the developing child. The exaltation of the human reason and the general sceptical nature of Locke's philosophy reappeared in the rationalism of Voltaire and his school.

Locke's pedagogical works *Some Thoughts Concerning Education* (1693) and *Of the Conduct of the Human Understanding* (1706) emphasized the importance of studies such as modern languages, the mother tongue, geography and mathematics. Locke described the

education of a gentleman, and his hypothetical boy was under the continual guidance of a tutor. At this time it was customary for the nobility to entrust the education of their sons first to a private tutor. The boys were usually sent abroad afterwards to one of the numerous academies where modern languages, geography and mathematics were taught, together with horsemanship and the use of arms, which were essential accomplishments for a gentleman of those days. The gradual modernization of the school curriculum was largely due to this practice of the nobility.

The claim of Locke to a prominent place in the history of education lies on his emphasis on the formation of character as the aim of education. In his scheme, the training of the reasoning powers was all-important, while the imaginative and emotional elements in the developing character received but scant recognition. In spite of the importance of the reason in Locke's scheme, he was no advocate of science teaching. He did, however, realize the value of manual dexterity, and urged that the young pupil should be taught a trade and enjoy the benefits of out-door life. More than fifty years later Rousseau, who owed so much to the inspiration of Locke, pleaded for a "natural education" as the birthright of every child, and all Europe resounded to the cry.

An interesting 18th century work on education is that of Thomas Sheridan: *British Education* or *The Sources of the Disorders of Great Britain*, published in London in 1756. Sheridan endeavoured to show that the existing defective education is the cause of ignorance, immorality and bad taste. He believed in the power of education to improve the whole social system. Grandiose schemes of education, however, did not appeal to Joseph

Priestley[1] (1733—1804), who pointed out the dangers arising from a stereotyped uniformity. The existing state of the universities was criticized by Vicesimus Knox[2] (1752—1821). His long residence at Oxford gave him an intimate knowledge of the lax methods by which degrees were obtained and his description of the wall lectures is well known. The possibility of a national scheme of education was discussed by Godwin[3] (1756–1836). He summarized the arguments for and against such a system, and concluded that any organized methods will retain the individual in a state of pupilage. He ridiculed the Sunday schools and every kind of public education then in vogue. This work, written during the last decade of the century, certainly shows that if Godwin's views reflected the opinions of the time, it is not surprising that popular education was of slow growth in this country.

16. *Some Influences in the Schools*

The religious question continually occurs when we consider the history of education. The legislation of Elizabeth's reign forced Roman Catholics to set up schools on their own account. The repressive measures passed during Restoration times, similarly drove the Protestant Nonconformists to establish schools outside the national system. Both the schools of the Jesuits

[1] Joseph Priestley, *Essay on the First Principles of Government, etc.* London, 1768

[2] Vicesimus Knox, *Essays Moral and Literary*, 3 vols. London, 1782.

[3] Wm. Godwin, *Enquiry Concerning Political Justice*, 2 vols. London, 1793.

and the Nonconformist academies found a place for the teaching of natural science earlier than the established Grammar schools.

The course of study for students in Jesuit schools was laid down in the *Ratio Studiorum.* This code had been drawn up in the period 1584—1599 and remained in force until revised in 1832. The studies for the third year students included Physics, Cosmology, Astronomy and Mathematics. The Physics, Cosmology and Astronomy were of the old Aristotelian order. Some work of a practical nature was, however, gradually introduced, and by the middle of the 18th century "physical cabinets" were in regular use in the Jesuit schools and experimental lectures were given.[1]

The Nonconformist academies of the 18th century, though primarily intended for the training of ministers of religion, received many pupils not so destined. A wide course of study was provided, including Greek and Latin, mathematics, modern languages and physical science.[2]

By the Act of 1779, Protestant Nonconformists were allowed to teach without restriction except in the universities and public schools. This resulted in the establishment of many new schools. The inclusion of scientific and other modern studies appealed to the wealthy merchants and manufacturers of the time who sent their sons to the private schools. Tuition in such schools, followed by a period of travel, was often substituted for a university education.

[1] Pachtler, *Ratio Studiorum, etc.*, 2 vols. 1887. Vol. III, p. 441.

[2] The schools of the Protestant dissenters are mentioned in Clarendon, *History of the Rebellion.* (1703.)

An imposing list of these Nonconformist academies from 1680–1770 is given in the *Cambridge History of English Literature*, Vol. X, p. 384.

We are told by one writer that experimental philosophy was "performed" at one of the private schools of London. A book intended as a means of supplementing the lectures was written by one Benjamin Worster and entitled *A Compendious and Methodical Account of the Principles of Natural Philosophy: As they are explained and Illustrated in the Course of Experiments performed at the Academy in Little Tower Street.* London, 1722. The subjects include machines, hydrostatics, the laws of motion, pneumatics and optics. The writer's style is dogmatic and probably at the time he was convincing. For example, he defines a ray of light as "a stream of ether emitted from a luminous body and proceeding in a right line until it meets with some obstacle." It is unfortunate that there is no description of the experimental demonstrations. It is interesting to note that the same lecturer "performed" a course of experimental philosophy "for qualifying young gentlemen for business." Here was an early recognition of the utilitarian value of a scientific education!

Characteristic of the 18th century was the gradual recognition of the need for educating the poor. The many philanthropic schemes were not wholly free from self interest, for the underlying and sometimes even the expressed aim was often to render the children of the poor harmless, well behaved members of society. The restricted curriculum of the charity schools established the tradition of the importance of the three R's.[1] The emphasis on these instrumental subjects we find dominated elementary education until the end of the

[1] The phrase the three R's is said to have originated with Sir Wm. Curtis (1752–1829), who once proposed a toast to Reading W(Riting) and A(Rithmetic).

19th century. This consideration has an important bearing on our subject as it accounts for the slow entry of scientific studies into the scheme of national education.

The story of the public schools during the 18th century has some chapters that are dark indeed. The numbers of pupils fluctuated considerably and this affected the universities. We hear of open rebellions at Winchester and Eton demanding the reading of the Riot Act.[1] The curriculum remained predominantly classical. According to a contemporary writer [2] such extra subjects as writing, dancing, French, drawing, fencing, were taught on half holidays. Is it not surprising that when such a multitude of subjects were regarded as means of relaxation or at least of profitable employment, no place could be found for such a pleasant extra as natural science ?

17. *Content of Science Teaching in the Universities*

The universities suffered many changes of fortune during the 18th century. The difficulties of internal government were apparent in the continual warfare between the university and the colleges. The last decades of the century witnessed great efforts for the abolition of religious tests. The intellectual life of both universities was for many years in a state of utter stagnation. We read of the escapades of bucks, bloods and smarts, and the frivolities of undergraduate life have a

[1] Vicesimus Knox, *Essays Moral and Literary*, 3 vols. London, 1782.

[2] Thomas James (1748–1804). His MSS. are given in Maxwell Lyte. *History of Eton College.* London, 1875.

lasting record in the water-colour drawings of Rowlandson.

The number of new chairs established during the century might seem to be evidence of activity. For instance, at Cambridge appointments to professorships were made in chemistry, astronomy (Plumian), experimental philosophy (Plumian), Anatomy, Botany, Arabic, Geology, and Geometry (Loundean). But we cannot conclude from the official appointments that there was necessarily any great development of science teaching. A professor of chemistry at Cambridge, Richard Watson (1737–1816), confessed to a complete ignorance of the subject at the time of his appointment.[1] But he tells us in his naïve way that by diligent experimenting for several hours daily in his laboratory he obtained such a command of the subject that large and distinguished audiences flocked to his lectures. Like other college dignitaries of his time he held simultaneously several appointments, being Regius professor of Divinity, Bishop of Llandaff and rector of several parishes. The chair that Watson held had been created by that fiery Master of Trinity, Richard Bentley (1662–1742), who, anxious to encourage the study of chemistry, had invited a Veronese Doctor Vigani (1650–1712) to come to Cambridge. In 1703 Vigani had begun his duties in a laboratory fitted up in an old cellar near the bowling green of Trinity. We gather from the diary of a Cambridge man that he learnt little or nothing from Vigani's lectures.[2] If Richard Watson is a typical example of his successors in the chair, we must conclude

[1] Richard Watson. *Anecdotes of the Life of Richard Watson.* London, 1818, p. 46.

[2] Chr. Wordsworth. *Scholæ Academicæ.* Cambridge, 1877, p. 188.

that chemistry teaching at Cambridge was slight indeed.

The physical sciences fared better at Cambridge owing to the magic of Newton's name. Until the middle of the 18th century the requirements for a degree consisted in disputations, as in medieval times. But in 1747 the Mathematical Tripos was instituted and mathematics became one of the chief studies at the university.[1] The evolution of the modern type of written examination was a slow process. Nevertheless the institution of the Tripos showed that Cambridge was beginning to set her house in order. It was not until 1850, more than a hundred years later, that the Natural Science Tripos was introduced. In the interval, however, the high place afforded to mathematics established a tradition which has been the glory of Cambridge ever since.

With regard to the content of natural philosophy teaching at Cambridge during the 18th century, we have records of schemes of study of which that of Robert Green, Fellow of Clare, is perhaps the most interesting. The following summary of the scientific part shows that contemporary advance received due recognition :—

First Year.

Second Half : 1. Chronology and Geography with a study of maps.

Second Year.

First Half : 1. Logic—Burgersdicius, Locke.
2. Geometry, Elements of—Euclid, Sturmius.

[1] An account of the early mathematical examinations is given in Wm. Whewell, *Of a Liberal Education*. London, 1844.

Second Half : 1. Arithmetic.
2. Algebra, Newton, Descartes, Wallis.
3. Corpuscular Philosophy, Descartes, Varenius, Boyle.

Third Year.

First Half : 1. Experimental Philosophy and Chemistry of Minerals, Plants and Animals. Philosophical Transactions, Boyle, Temmery.
2. Anatomy of—
(*a*) Animals : Keill, Gibson, Harvey, etc.
(*b*) Plants and Vegetables : Grew. Philosophical Transactions.
(*c*) Minerals : Hooke's Micrographia, Leeuwenhoek.

Second Half : 1. Opticks, Dioptricks, Catoptricks, Colours, Iris : Newton, Descartes, Kepler, etc., Gregory, Huygens, Barrow.
2. Conick Sections and the nature of curves : Newton, Wallis, etc.

Fourth Year.

First Half : 1. Mechanical Philosophy, Staticks, Hydrostaticks, Flux and Reflux, Percussion, Gravitation, etc. : Marriot, Huygens, Boyle, Newton, Wallis, etc.
2. Fluxions, Infinite series, Arithmetic of Infinites : Wallis, Newton, etc.

Second Half: Astronomy: Flamsteed, Newton, Kepler. Logarithms and Trigonometry.[1]

According to Desaguliers (1683–1744)[2] the first to teach physics in Oxford by means of experiments was John Keill, who began a course of lectures about the year 1704 designed to teach the Newtonian Philosophy by means of actual demonstrations. At the same time, chemistry lectures were given in the Ashmolean by John Freind of Christ Church.[3] These were afterwards published under the title *Chymical Lectures in which almost all the Operations of Chymistry are reduced to their True Principles and Laws of Nature*, 1704. (Englished by J. M. London, 1712.) He explains that his aim in expounding chemistry is "to bring a little plain sense into an art, which the professors of it would never yet suffer to appear in any other dress than that of fable and jargon." He claims that from Archimedes to Galileo, important truths have been brought to light without the invoking of any hypothesis. He emphasises the need for experiment and for accurate descriptions of phenomena and shows the futility of those hypotheses, which involve what he calls "occult qualities which confound the principles of true philosophy and reduce it to its ancient chaos."

He cites as an instance the idea of Linus that the mercury in a Torricellian tube becomes stretched at the surface into a subtle kind of matter which like a

[1] Robert Green, *A Scheme of Study*, 1707, in Chr. Wordsworth, *Scholæ Academicæ*, Appendix IV. Cambridge, 1877, p. 338.

[2] J. T. Desaguliers, *A Course of Experimental Philosophy*. London, 1734.

[3] R. T. Gunther, *Early Science in Oxford*. Oxford, 1922. Vol. I, pp. 52–63.

Funiculus holds up the whole column. These "attractive funicles," he says "are mere figments of the imagination."[1]

The series of lectures delivered by Martin Wall,[2] Public Reader in Chemistry to the University of Oxford, are of particular interest in that they are evidence of the established views on the subject towards the close of the century. He gives a syllabus of lectures dealing with the origin of the science of chemistry, the history of alchemy, and the best way of delivering lectures on chemistry. He expounds the theory of latent heat and describes the chemical experiments of Boyle, Margraff, Priestley, Scheele, Boerhaave, Lavoisier and Cavendish.

Although these glimpses of early science teaching are of interest, yet we must remember that all the original work of importance was done independently of the universities and that at this stage there was no conception of the universities as centres of research.

18. *Some Individual Efforts for Scientific Instruction*

The great number of books on natural philosophy, published during the 18th century,[3] affords some evidence of a demand on the part of the reading public. Some of the works of Desaguliers[4] were expressly written for

[1] The arguments of Linus and of Descartes on Nature's abhorrence of a vacuum are refuted by John Wallis in his *Discourse on Gravity and Gravitation founded on experimental observations.* 1674. p. 33.

[2] Martin Wall, *Dissertation on Select Subjects in Chemistry and Medicine.* Oxford, 1783.

[3] Watt, *Bibliotheca Britannica* enumerates some 70 English works on Natural Philosophy published during the 18th century.

[4] For instance: *Physics and Mechanical Lectures or an Account of what is explained and demonstrated in the Course of Mechanical and Experimental Philosophy* given by J. T. Desaguliers, M.A., F.R.S. London, 1717.

those with no mathematical equipment, and were addressed to the private reader. Desaguliers illustrated his lectures by experiments and he showed how to find the focal length of lenses and the refractive indices of liquids. The note at the end of one of his published courses of lectures states that the fee for "going through the course" was three guineas.

Among the earliest 18th century works on science those of John Harris are of particular interest. His vast *Lexicon Technicum* is an encyclopædia covering the whole range of existing scientific knowledge and its application to the arts and manufactures. His work on astronomy is entitled *Astronomical Dialogues between a Gentleman and a Lady wherein the Doctrine of the Sphere, Uses of the Globes and the Elements of Astronomy and Geography are explained in a pleasant, easy and familiar way.* (London, 1719.) He explains eclipses of the sun and moon and describes the Orrery constructed by a certain John Rowley, "Master of Mechanics to the King." The following sentiments expressed by the good lady of the dialogues exemplify the pleasant way in which Harris instructs his readers in astronomy:—

"That word *world*," said she, "I can't get over without reflecting what weak, vain and silly mortals we are. We too often take this poor spot of earth to be the only world worth enquiring after, and so we can acquire a little of its dirt, we neglect all care for an Eternal Mansion in the Heavens. And further, I have no patience with Ptolemy, and his Astronomers, that will needs have the mighty sun and all that infinite orb of the Fixed Stars to be made only for the sake of this dirty little planet."

Enterprising individuals often gave scientific lectures

to adult audiences. One course of lectures was "performed over the Bedford Coffee House, Covent Garden" and illustrated by experiments.[1] The syllabus of the lectures shows that experimental demonstrations were frequently given. For instance, there were experiments to show that the path of a projectile is a parabola, that "fluids press in all manner of directions at the same time," and that "sound cannot be conveyed without air."

In the days when university teaching in science was so slight, when travel was difficult, and when scientific periodicals were few, men interested in science used to form themselves into clubs for discussion and for teaching. One such club, the *Lunar Society* of Birmingham, flourished for 40 years and included many famous names among its members.[2] This club was founded in 1766 by Erasmus Darwin (1731–1802) and some friends. The members used to meet on the Monday nearest the full moon, as this enabled them to have the safety of the moonlight as they dispersed to their homes, no unimportant matter in the days of foot-pads. Priestley (1733–1804), Watt (1736–1819), Josiah Wedgwood (1730–1795), Sir Joseph Banks (1743–1820), and W. Herschel (1738–1822) were prominent members. The Lunar Society played an important part in the spread of scientific knowledge among the people of the midlands.

Another still earlier instance of individual endeavour comes from Manchester. We read of peripatetic lectures on Natural Philosophy financed by public subscription. We select as an example, the course

[1] J. T. Desaguliers. *A Course of Mechanical and Experimental Philosophy.* London, 1727.

[2] *Scientific Correspondence of Joseph Priestley.* New York, 1842, p. 195.

given in 1743 in Manchester by Samuel Kaye, M.D. (1708–1782).[1]

Lecture 1. General Introduction. Reference to work of Descartes and other Natural Philosophers.
2. Divisibility of matter. Attraction and repulsion. Gravitation and Cohesion.
3. Repulsion of matter. Electricity. Phosphorus.
4. Mechanism of air pump. Boyle, Papin.
5. Motion. Momentum.
6. Weight. The Lever, the pulley, etc.
7. The Inclined Plane, wedge and screw, compound engines.
8. Sir Isaac Newton's Laws of Nature.
9. Gravitation. Projectiles.
10. The tides.
11. Hydrostatics.
12. Weight of different fluids.
13. Of spouting water and of specific gravity.
14. Pneumatics.
15. Pneumatic Engines. The Air Pump.
16. Elasticity of the Air, the Human Diaphragm.
17. Further experiments in Pressure and Elasticity of Air.
18. Optics.
19. Reflection of Light and Laws by which it is accomplished.
20. The Eye and the nature of Vision.
21. Theory of Colour. Sir Isaac Newton's views.
22. Of the Orrery.

[1] A. A. Mumford. *Manchester Grammar School.* London, 1919, pp. 157–158.

23. Of the Earth and its Motions.
24. Of the Planets.

The following advertisement in the *Manchester Mercury* for 1762 is also of interest.

> A Course of 20 lectures on Experimental Philosophy to be given at the late Angel Inn, Market Place, by James Ardenn, Teacher of Experimental Philosophy at Beverley. Natural History, Mechanics, Astronomy, Geography, use of Globes, Hydrostatics, Pneumatics, Optics.

Towards the close of the 18th century there existed quite a large number of local societies for the encouragement of scientific and literary studies. They were due entirely to individual enterprise and were supported by the subscriptions of members. Of these societies, the Literary and Philosophical Society of Manchester is perhaps the most renowned.

The *Literary and Philosophical Society* of Manchester was founded in 1781. The conditions for membership included the publication of literary and philosophical works. More than half the original members were medical men and several were Fellows of the Royal Society. Among the first honorary members we find the names of Franklin, Priestley, Martin Wall and Volta.[1]

The most distinguished officer the Society ever had was John Dalton (1766–1844). Dalton came to Manchester in 1793 as Tutor in Mathematics and Natural Philosophy at the Manchester Academy, a small private college for Dissenters. Here he carried out his investigations on the artificial production of cold,[2] and began his

[1] *Memoirs of the Literary and Philosophical Society of Manchester.* Vol. I.
[2] *Meteorological Observations and Essays.* 1793.

work on colour vision.[1] Dalton held office from 1800 until his death, first as Secretary, then as Vice-President, and finally as President.

Two years after its foundation, the Society issued its first *Memoirs*. The publication did much towards the spread of scientific knowledge at a time when periodicals were few. Dalton and, later, Joule (1818–1889) published much of their work in the Society's *Memoirs*. Early in the 19th century the Society arranged for the regular delivery of lectures. Separate sections were formed and the work of the Society assumed a more specialised form.[2] In later times we find among the lists of members such famous names as Richard Cobden, Sir Joseph Whitworth, R. C. Christie, Sir Henry Roscoe, Osborne Reynolds, Carl Schorlemmer, and Balfour Stewart. The noble traditions of the Society have been preserved unbroken and at the present time valuable work is still being carried on.

The growing interest in the practical applications of science evident in the last decades of the 18th century was due in a large measure to the publications of the *Society of Arts* of London. This Society was founded in 1754 for the "encouragement of the arts, manufactures and commerce" of the country. Exhibitions of scientific curiosities were arranged under its direction, and in the 19th century the society introduced a system of examinations covering a wide range of subjects.

The adverse effect of labour-saving machinery and the resultant division of labour had been realized by Adam Smith (1723–1790). In his *Wealth of Nations* he

[1] *Extraordinary facts relating to the Vision of Colours.* Memoirs, Vol. V.
[2] See a pamphlet by F. Nicholson. *The Literary and Philosophical Society.* Manchester, 1924.

contrasted the intelligent outlook which results from a variety of occupations with the deadening "torpor of mind" after the result of a life spent in single routine operations. His remedy was education for all. The instances of individual efforts we have cited show that Adam Smith reflected the general view of the more enlightened thinkers of his time. The demand for purely scientific knowledge which showed itself in the closing years of the century resulted in the formation of the well-known Mechanics Institutes.

19. *Science in England during the Eighteenth Century*

In physical science, the philosophers of the time made use of the notion of imponderable fluids to explain many phenomena. The corpuscular theory of light had accustomed them to think of streams of corpuscles given off from a body without making any difference to its weight. Another "imponderable," *Phlogiston*, was invoked to explain certain phenomena of combustion. Our English chemists Priestley (1733–1804) and Cavendish (1731–1810) were both upholders of the Phlogiston theory. The relationship between light and heat led to the conception of a heat substance or *caloric*. In the hands of Black (1728–1799) the theory proved a valuable instrument of research, and he was thereby led to actual measurements of specific and latent heat.

We find electricity described as an effluvium[1] given

[1] The *Lexicon Technicum*, 1704, of John Harris describes *effluviums* as "small particles or corpuscles continually flowing out of all mixt bodies without any sensible diminution of the bulk and weight of the body that emits them."

off from a charged body and sometimes as one subtle fluid, sometimes as two. Despite the phrasing of the hypotheses important facts regarding charged bodies were brought to light by the obscure worker Stephen Gray and by William Watson (1715–1787). Electrical machines were devised by Watson, Priestley, and by Abraham Bennet (1756–1799), the inventor of the gold leaf electroscope. Priestley inferred the law of inverse squares. Profound investigations in electricity were made by Cavendish, but owing to his curious methods, he did not influence science teaching at the time.

It is important to note that no work of outstanding importance was produced at the universities. It was by amateurs in different stations of life that these far-reaching discoveries were made. Cavendish was one of the wealthiest men of his time. Priestley was a Nonconformist minister. Watson began life as an apothecary. Bennet and John Michell (1718–1793), who invented the torsion balance, were country clergy. John Canton (1718–1772), the inventor of the influence machine, was a private schoolmaster. Astronomy attracted many amateurs of whom the outstanding figure was William Herschel (1738–1822), originally a teacher of music.

The 18th century witnessed the direct application of science to the production of mechanical power by James Watt (1736–1819) following on that of Newcomen (1663–1729), an instrument maker. The foundations of the branch of hydraulic engineering were laid by Bramah (1749–1814). At the close of the 18th century, the practical application of science to industry was occupying much attention. Improvements had been made in the construction of the air pump, the barometer, thermometer, and pendulum clock. Optical

instruments had revealed a complexity of matter hitherto unrealized. Accurate observations led to an extension of knowledge of the plant and animal worlds. The discoveries of the English chemists from Mayow to Cavendish were systematized and extended by Lavoisier. The time was now ripe for the universities to take an active part in the search for truth, but they lagged behind, and the real academic development of science did not begin until more than fifty years later.

Chapter V

Nineteenth Century—Science Teaching in the Universities and Other Institutions for Higher Education

20. *The Royal Institution*

THE 19th century witnessed the rise and decay of many efforts for scientific instruction. One of the most important and most enduring was the Royal Institution. Its foundation was due to Count Rumford (1753–1814), that versatile philanthropist and man of science. The application for its Charter in 1799 was "For forming a Public Institution for diffusing the knowledge and facilitating the general introduction of useful mechanical inventions and improvements, and for teaching by courses of philosophical lectures and experiments the application of science to the common purposes of life."[1] It was granted in the following year and extended in 1810.

Rumford had always been interested in problems of domestic economy and we find him making plans for providing model fire-places, ventilators and cooking utensils as well as models of lime kilns, boilers, spinning wheels and looms.[2] He worked indefatigably during the early days of the Institution, supervising the building operations and arranging for the equipment of the

[1] Bence Jones, *The Royal Institution.* London, 1871, p. 136.
[2] *ibid.* p. 116.

workshops and laboratories. Rumford intended the Institution to be a means for training young men in the mechanical professions. He proposed that the young students should be boarded and lodged in the Institution for some three or four months, and so acquire a " perfect knowledge of new and useful inventions applicable to the common purposes of life." The practical character of the instruction to be given was always emphasized and indeed the professors were exhorted to exclude all abstract and mathematical reasoning as far as possible.

With regard to the definitely scientific side of the teaching the managers of the Institution proposed to have a " lecture room and a complete laboratory . . . with the necessary instruments for making chemical and philosophical experiments " under a professor of Natural Philosophy and Chemistry.

The journal issued by the Royal Institution [1] gives us an interesting glimpse of contemporary science during the early years of the 19th century—the managers were so anxious to keep in touch with movements abroad that continental scientific journals were sent over still wet from the press. In the early days Rumford lectured on means of increasing the heat from the combustion of different fuels and on the use of steam in conveying heat, but the lectures which drew the most public attention to the Royal Institution were those given by Humphry Davy (1778–1828). Rumford had indeed rendered a great service to science when in 1801 he invited Davy to leave the *Pneumatic Institution* at Bristol and come to the Royal Institution as lecturer in Chemistry and Director of the Laboratory.

The subjects to be investigated were prescribed by

[1] *The Journal of Science and the Arts.* Published quarterly.

the managers who, after the manner of their kind, hampered their eagle with leaden weights. The professor had to be "practical," and Davy had to turn his attention first to the art of tanning and then to agriculture. But soon after his appointment, the interest of the scientific world was centred on the phenomena of the voltaic pile, and by 1806 Davy had freed himself from that perpetual nuisance in science, the co-called "practical" man, and had made some important investigations on electrolytic decomposition.

But by the time these researches were in progress the organization of the Royal Institution had been placed on a different basis. Rumford had returned to Munich in 1802. As soon as he was safely out of the way the plans for the instruction of young mechanics were abandoned. Financial difficulties compelled the managers to revise the schemes in the first instance, but Rumford's domestic economy and philanthropic projects for teaching the useful arts had never appealed to them. Gradually the Royal Institution became a centre for the spread of scientific knowledge among the more cultivated sections of the community. Davy's lectures attracted fashionable London. The Friday evening discourses instituted by Faraday (1791–1867) and the Christmas lectures for children became an established part of the tradition.

Yet it was not until the second half of the 19th century that science secured a recognized place in the universities and a standard of academic teaching became established. Consequently the teaching given at the Royal Institution during the first half of the century cannot be described as popular in our modern sense of the word. The early teaching was not a talking down to the multitude, but a veritable preaching of the gospel of physical science.

The Royal Institution has been associated with the investigations of Thomas Young, Davy, Brand, Faraday, Tyndall and Frankland, and within recent times the researches of Dewar, Lord Raleigh, J. J. Thomson, Rutherford and Bragg have been carried out within its walls. We need not regret that the original schemes of Rumford came to nought, because for that very reason the Royal Institution has been enabled to make a unique contribution to scientific education in this country.

21. *The Mechanics Institutes*

The beginning of a system of education for working men was due to John Anderson (1726–1796) of Glasgow. He was professor of Natural Philosophy and used to hold evening classes in 1760 to which workmen were invited. Anderson left the whole of his property to found a university in which science should hold the chief place. His wealth was bequeathed for "the improvement of human nature, of science and of his country." Evidently Anderson was not disturbed by any doubts as to the reality of progress. Unfortunately his estate realized only £1,000. This was hardly sufficient to carry out his good intentions. The sum was, therefore, devoted towards the founding of a chair of physics at Glasgow University.

The first to hold the new appointment was George Birkbeck (1776–1841). Apparatus was needed for the teaching of physics and much had to be constructed under the direction of Birkbeck himself. The instrument makers and artisans employed for this purpose showed

such an intelligent interest in the work that Birkbeck invited them to his lectures. Many of the men availed themselves of this opportunity and he was obliged to form separate classes, in a building which became known as *Anderson's Institution.*

The organization continued successfully even after Birkbeck left to take up a medical practice in London. In 1823 the men formed themselves into an independent body. Their action was followed in other great towns, and in this way arose the *Mechanics Institutes.* Their establishment represents an important and interesting movement.

One of the foremost advocates of popular education in the early 19th century was Lord Brougham (1778–1868). At a time when the wave of enthusiasm for the Mechanics Institutes was at its height, Brougham wrote a pamphlet which went through twenty editions in the first year, 1825. In characteristic fashion, Brougham swept aside the difficulties encountered by the Institutes. He even suggested that the workmen might have a boy to read to them while at work, and that specially prepared treatises, or short cuts to knowledge, might be put into the workmen's hands. He assumed that the artisans would have enough leisure for two or three hours reading a day and that they could afford the modest fees required for the lectures. Lecturers, Brougham thought, might often give their services for nothing. As regards apparatus for experimental teaching, he pointed out that only simple materials would be required, Franklin having ascertained the nature of lightning with the aid of a key, a kite and a piece of string.[1]

[1] H. Brougham, *Objects, Advantages and Pleasures of Science.* The Pamphleteer. London, 1826, p. 14.

Brougham was the first president of the *Society for the Diffusion of Useful Knowledge*, founded in 1827. The Society's publications included the *Penny Magazine*, *Penny Enclyclopædia* and numerous cheap books written by the best writers of the time, which might have been designated as " Science without tears." These excellent publications, which counted such men as Augustus de Morgan among the contributors, secured a large circulation and were possibly the kind of books that Brougham would have recommended for the mechanics to use in their leisure hours. The extent of Brougham's own knowledge of science and of contemporary achievements may be inferred from the fact that he described as " slight and trifling " the work of Thomas Young (1773–1829), that genius whose range of knowledge and insight was so amazing. Brougham, however, did much to popularize the Mechanics Institutes. They multiplied steadily, and by 1850 were more than 600 in number and had over 100,000 members.[1] The Institutes frequently combined into unions and arranged for the interchange of lecturers and the loan of books and exhibits.[2] To assist the travelling lecturers, the " Working Man's Educational Union " prepared sets of diagrams on such diverse subjects as the Antiquities of Nineveh, Astronomy, The Telescope, Pagan Rites, etc. This Union also published a little manual " Practical Hints to Unpractised Lecturers to the Working Classes," [3] which may still be read with profit by many. Stocks of written lectures were kept and loaned out as occasions arose.

In 1852 the *Society of Arts* (see Chapter IV) formed

[1] J. W. Hudson, *History of Adult Education.* London, 1851. Preface.

[2] J. Hole, *Prize Essay on Literary and Scientific and Mechanics Institutes.* London, 1853, pp. 120, 130.

[3] " *Practical Hints to Unpractised Lecturers to the Working Classes*," p. 150.

a union of Mechanics Institutes [1] and proposed to hold examinations to qualify for membership. This naturally chilled the enthusiasm of the young artisans and we are told that only one candidate presented himself in the year 1855.[2] In the course of a few years, however, the system became established. The papers set included the subjects of chemistry, physiology, botany, mathematics, and mechanics. The examinations were intended for students who had left school and who were at least 15 years of age. A volume containing hints to students was published under the auspices of the Society of Arts on *How to Learn and What to Learn.*

The action of the Society of Arts in promoting such examinations awakened the interest of the Universities—and this led to the organization of local examinations by both Oxford and Cambridge. These we will consider in a subsequent chapter because of their more direct bearing on schools. The Mechanics Institutes undoubtedly helped forward the cause of scientific education during the first half of the century. They not only supplied an intellectual interest to the working man but they helped to spread some knowledge of science among a section of the community who would otherwise have remained ignorant.

As time went on the character of the institutes underwent a change. The members were no longer drawn from the ranks of the artisans, and the meetings became occasions for social activities and intellectual amusements. A balanced view of the Mechanics Institute written in the fifties [3] reveals the cause of the decline. The work

[1] *Journal of the Society of Arts.* 1852, p. 2, 1854, p. 823.
[2] *Journal of the Society of Arts.* 1859, p. 194.
[3] James Hole, *An Essay on the History and Management of Literary, Scientific and Mechanics Institutions, etc.* London, 1853.

was crippled for lack of funds. There was no natural system of education at that time, and the young artisans had first to learn what they should have mastered at an elementary school. The rise and fall of the Mechanics Institutes marks an important phase in 19th century history. The institutes were the concrete result of individual enthusiasm and endeavour. They achieved a measure of success long before there was any state aid for education. In the days of their decline it was realized that an attempt had been made to build on insecure foundations. The easy optimism which could write complacently on the *Results of Machinery*[1] and ignore the actual conditions of the workers had to give place to a more philosophical view.

The general spread of education and the rise of competent teaching bodies, such as the newer university colleges, set a high standard of scientific education. Consequently the more ambitious students were no longer content with the humble Mechanics Institutes. It is of interest to note, however, that one of the largest of such institutes in London, the Birkbeck Institution, which for many years provided lectures on literature and science for working men, has now become a school of the University of London. Birkbeck College, as it is now called, provides university teaching which is given mainly in the evenings. In this way Birkbeck College keeps its doors open to students who have to earn their living during the day Thus the college perpetuates the traditions of the early Mechanics Institutes and commemorates the good work of Birkbeck.

[1] Written under the auspices of the *Society for the Diffusion of Useful Knowledge*. See *The Results of Machinery, Namely Cheap Production and Increased Employment*. London, 1831.

22. *Further Efforts for the Spread of Scientific Education*

The number of societies devoted to the popularization of scientific knowledge during the 19th century is so great that we can illustrate the movement only by the selection of a few of the most interesting and typical.

We have already mentioned the Literary and Philosophical Society of Manchester. Similar societies sprang up in nearly all the great towns during the 19th century. Some were merely scientific amusement clubs, others provided definite instruction and were largely instrumental in spreading the desire for higher education which resulted in the establishment of the provincial universities. The importance of the many scientific societies ranging from the learned bodies to the humble naturalist clubs was emphasized at the British Association Meeting of 1879.[1]

One of the most important agencies for the spread of scientific knowledge in the midlands in the second half of the century was the Birmingham and Midland Institute. This was founded in 1853 for the education of artisans and miners in the principles of their daily occupations. The institute consisted of a General Department and a School of Industrial Science. Under the first was included the management of libraries, museums of natural history and geology, the keeping of mining records and the organization of lectures on general scientific subjects. The School of Industrial Science organized class instruction in chemistry, mechanics, mineralogy and geology, all with a distinctly practical bias. Another example is afforded by the town

[1] Report, 1879. *The scientific societies in relation to the Advancement of Science in the United Kingdom*, pp. 458–468.

of Halifax. Here a Literary and Philosophical Society was established in 1830 and a separate Scientific Society in 1874. Both societies are still flourishing.

A type of evening class different from that provided by the Mechanics Institutes or the local scientific societies was established by the various *Working Men's Clubs*. These clubs originated in the Chartist and Christian Socialist movements. The first of the Working Men's Clubs was the *People's College of Sheffield* founded in 1842. A wide curriculum including the classics was provided and the classes were held in the early hours of the morning before the work of the day began, and also in the evening. The fees were 9d. per week and membership was open to all men and women over sixteen years of age.[1] Public lectures were given on chemistry as applied to the cutlery trades and students took the Society of Arts examinations in chemistry. The People's College was the means for receiving and dispensing more than £4,000 for the promotion of popular education during the ten years 1848–58, and through many temptations steadily held to the principle of self support.[2]

Following the example of Sheffield, a *Working Men's College* was founded in London in 1853 by F. D. Maurice and a group of friends. For a few years the college was housed in Red Lion Square. Although science held an important place in the curriculum, the most distinguished teachers dealt with the æsthetic subjects. We find among the lecturers the names of Ruskin, Dante Gabriel Rossetti, Charles Kingsley and Ford Madox Brown.[3]

[1] T. Rowbotham, *Working Men's College Magazine*. 1859. Vol. I, pp. 71, 98–101.

[2] *ibid.*, p. 98.

[3] There is a history of the college by J. Ll. Davies, *The Working Men's Magazine*, 1854–1904. London, 1904.

Similar colleges were founded in many of the great towns. For instance one was founded at Cambridge in 1857, at Wolverhampton in 1857, in Salford in 1858 and in Liverpool in 1860. An interesting little volume dedicated to F. D. Maurice gives a survey of the progress of many of these clubs. Apparently the organizers found it difficult to maintain the interest of their audiences. We are told, for instance, of a lecture on The Hand, the Hoof, and the Wing (founded on the Bridgewater treatise of Sir Charles Bell) that had to be enlivened by "recitations and songs given in a pleasant style."[1] Moreover the committee responsible for the lecture took care to advertise it as an evening's entertainment.

This is by no means the only instance of audiences being bribed with the promise of amusement. The instruction given at the *Surrey Institution* near Blackfriars Bridge, which attracted such large gatherings in the early years of the century, was well adapted to the varied tastes of the people.[2] *The Society for the Illustration and Encouragement of Practical Science* found it necessary to advertise its exhibition held in the Adelaide Gallery . . . as a means for "blending instruction with amusement." Indeed the heterogeneous collection of oddments exhibited there must have provided more amusement than instruction.

23. *University Reform and the Official Recognition of Science*

From 1800 until 1850 the universities were subject

[1] H. Solly, *Working Men's Social Clubs*. London, 1867, p. 257.
[2] Rowlandson and Pugin, *Microcosm of London*. Vol. III, p. 154.

to ruthless criticism. The first open attacks were made in the *Edinburgh Review.* In an article dealing with the *Mecanique Celeste* of Laplace, the writer deplored the lack of English names among the great mathematicians and physicists of the last 60–70 years. The writer went on to say:—

> "We believe that it is chiefly in the public institutions of England that we are to seek for the causes of the deficiency now referred to, and particularly in the two great centres from which knowledge is supposed to radiate over all the rest of the island. In one of these where the dictates of Aristotle are still listened to as infallible decrees, and where the infancy of science is mistaken for its maturity, the mathematical sciences have never flourished, and the scholar has no means of advancing beyond the merest elements of geometry . . . In the other seminary mathematical learning is the great object of study, but still we must object to the method in which the subject is pursued."[1]

Such an indictment of Oxford learning drew forth a spirited reply from Edward Copleston (1776–1849),[2] then a Fellow of Oriel and afterwards Bishop of Llandaff. Further criticisms and replies followed. The leaders in the attack were Playfair, Jeffrey and Sidney Smith, referred to by Newman as the "three giants of the North." Although Oxford regarded Copleston as her gallant defender, yet a careful study of the arguments of the defence show that the attacks were justified. From 1831–1836 Sir William Hamilton (1788–1856)

[1] *Edinburgh Review.* Vol. xi, p. 279.

[2] Copleston. *A Reply to the Calumnies of the Edinburgh Review against Oxford.* Oxford, 1810.

attacked the universities from the pages of the *Edinburgh Review*. Sir William Hamilton, before his appointment to the Chair of Philosophy at Edinburgh, had studied at Balliol. His complaints of the neglect of science at Oxford were based on personal experiences. Cambridge, as we have seen, emphasized the importance of mathematics by the introduction of the Mathematical Tripos in 1747–8. The powerful Master of Trinity, William Whewell (1794–1866) published a pamphlet dealing with the importance of a mathematical training.[1] This provoked Hamilton to further eloquence, and Cambridge was accused of fostering the study of mathematics to the exclusion of everything else.

Naturally the universities resented outside criticism, and we have seen that there had been some reform from within during the closing years of the preceding century. Until the end of the 18th century, however, Oxford gave its degrees without examinations to all who paid their fees and kept the required number of terms. To keep to the letter of the law the Presiding Examiner, the Candidate and the Opponents met together, but spent the statutory time in reading novels. But in 1800 Oxford passed a statute instituting examinations for degrees, thus following the example of Cambridge. This important reform was due to Jackson, Dean of Christchurch from 1783 to 1809, Parsons, Master of Balliol from 1798 to 1813, and Eveleigh, Provost of Oriel from 1781 to 1814. At first the examinations were optional, but in a few years they became compulsory, with three classes of honours and a separate pass examination.

[1] Whewell. *Thoughts on the Study of Mathematics as part of a Liberal Education.* Cambridge, 1835.

There was very little science teaching at the Universities in the early 19th century in spite of the official recognition of certain Chairs. Thus although a chair of chemistry had been endowed in 1803 by the Aldrich Trust the first two professors, Kidd (1775–1851) and Daubeny (1795-1867), did not succeed in attracting many students to their lectures. Daubeny, who succeeded to the Chair in 1822, lectured on chemistry, botany and rural economy and spent much of his time in his physic garden. We are told that "no other science was even nominally represented except experimental philosophy which meant lectures in the Clarendon by cheery Mr. Walker, who constructed and exploded gases, laid bare the viscera of pumps and steam engines, forced mercury through wood blocks . . . and manipulated galvanic batteries."[1]

Lyell relates how in 1839 the professors of experimental philosophy, comparative anatomy, chemistry, mineralogy, geology, botany, sent in a petition to the heads of houses begging to be excused from the obligation of giving lectures as so few students presented themselves. Again when Baden Powell (1796–1860) was appointed Savilian Professor of Geometry in 1827, Copleston advised him not to lecture as he would not be able to get together an audience.[2] At this time science was regarded with mild contempt or indifference. The fossil-hunting of Buckland (1784–1856) merely provoked Keble to remark that "When God made the stones He made the fossils in them . . ." This was at a time when the work of such men as Buckland was regarded as a harmless hobby.

[1] W. Tuckwell, *Reminiscences of Oxford.* Oxford, 1900, p. 41; and see R. T. Gunther. *Early Science in Oxford.* Oxford, 1922. Vol. I, pp. 71–86.
[2] W. Tuckwell, *Pre-Tractarian Oxford.* Oxford, 1909, p. 167.

It was not until years later that the real warfare between theology and science began.

But already there were warnings of another storm. The question of university reform had been raised in Parliament. In spite of the eloquence of the cloistered deans of Oxford, a Liberal Government authorized a Royal Commission in 1850. Before the Commission sat, a plea for reform had come from an Oxford man himself, Mark Pattison (1813–1884).[1] Mark Pattison belonged to the group of Broad Churchmen who helped to prepare the way for an appreciation of the great scientific advances of the second half of the century. His fair attitude smoothed away some of the difficulties provoked by the Royal Commission. The subsequent Acts of 1854 and 1855 effected an entire change in university constitution. Obsolete statutes were repealed and the way was open for a wider curriculum and a modern system of teaching.

In 1850 honours schools in Mathematics, Natural Science, Law, Modern History and Theology were instituted at Oxford. At Cambridge the Classical Tripos was introduced in 1824, the Moral Science Tripos in 1848 and the Natural Science Tripos in 1851. But in spite of this official recognition of natural science in both universities, the number of students presenting themselves was at first very few. It was not until the establishment of the Clarendon Laboratory at Oxford and the Cavendish Laboratory at Cambridge that great advances in the study of science began (see page 132).

In 1872 the University Extension movement was established by Cambridge through the influence of James Stuart, who afterwards founded the Cambridge

[1] Mark Pattison. *Suggestions on Academical Organization.* 1868.

School of Engineering. The example of Cambridge was followed by the University of London in 1876, and by Oxford in 1877. The newer universities followed the examples of Cambridge, Oxford and London.

The lectures to large adult audiences arranged under the University Extension schemes lent themselves better to the teaching of literature and history than science. However, for some years popular science lectures illustrated by experiments were quite successful. In the early days of the movement the lecturers were on the staff of the universities and were usually busy with investigations of their own. This brought the university atmosphere into the lecture rooms. Towards the close of the 19th century, however, the provision of technical institutes and the opportunities for small groups of students to work in the laboratories resulted in a decline in the popularity of the science lectures. At present the most successful courses in science seem to be those which treat of its history and philosophy.

24. *State Aid for Science*

In 1836 a select Committee of the House of Commons [1] appointed to enquire into the best methods of encouraging the fine arts, recommended the establishment of a Normal School of Design. A sum of £1,500 was voted for this school. In a few years time there were several provincial schools of design receiving part of this government grant. In 1852 a Department of Practical Art was formed. To this in the following year

[1] *Reports.* Parliamentary Papers. 1835, V.; 1836, IX.

a Science Division was added and the name changed to the *Department of Science and Art.*[1] The new department was administered first from Somerset House, but in 1857 it was removed to South Kensington. Huxley considered the establishment of this *Science and Art Department* as "a measure of more importance to the welfare of the people than many political changes over which the noise of battle has rent the air."

At this time there was a feeling of dissatisfaction with the whole system of education. The Great Exhibition of 1851 had shown the need of British Industries for specialized scientific training.[2] Now Parliament granted money for the encouragement of science teaching willingly enough. Examinations were organized by the Science and Art Department and grants were available for schools presenting successful pupils. No results were forthcoming, and it gradually dawned upon the official mind that science teachers would be necessary for the working of the scheme. These were not to be found. Accordingly in 1859 the Science and Art Department instituted a special examination for teachers. The institution of an examination is the traditional English method of encouraging a subject. But the interest in the subject among school managers had in the meantime waned. Thus, as teachers succeeded in qualifying themselves, there was not sufficient demand for their services. We are told that John W. Judd, the geologist, obtained first-class certificates in geology and mineralogy, but

[1] F. Ware. *Educational Foundation of Trade and Industry.* London, 1901, p. 29.

[2] An interesting contemporary view is given in Whewell's Lecture. *The General Bearing of the Great Exhibition on the Progress of Art and Science.* London, 1852.

was unable to find employment as a teacher of science, and was a country schoolmaster in general subjects for some years before he became a member of the staff of the Royal School of Mines.

The remuneration of the teachers of science depended on the number of pupils who passed the special examination set by the Science and Art Department, and additional fees could be claimed if the pupils obtained prizes. The system resulted in wholesale cramming for examination. Moreover many teachers in day schools who found their meagre salaries reduced because they did not produce the results demanded by Lowe's *Revised Code* succeeded in earning a little extra money by qualifying themselves as science teachers and then giving evening instruction in science themselves.[1] Under such circumstances we can realize how uninspiring and unsatisfying such early science teaching must have been.

The term " Science School " was at this time applied to any school, or part of a school, which earned South Kensington grants. Certain Mechanics Institutes availed themselves of the grants and by 1867 there were 212 " Science Schools " and 10,230 students.[2] At this time more instructors were available and the special examination for teachers was abolished. Some standard of general education, however, was demanded and the teachers were encouraged to avail themselves of the opportunities for study that London afforded. Many self-taught students collected South Kensington certificates by the dozen. There is a legend that the highest number of certificates in Agriculture were gained by earnest young men who had never stirred

[1] *First Report of Royal Commission on Scientific Instruction*. 1872, p. xx.
[2] *Report of Science and Art Department*. 1867.

beyond the precincts of Whitechapel. Naturally those students who had no help from teachers had to depend on text books. As examples of text books on science available at the time we may note the publication of Liebig's works on chemistry between 1835 and 1859 and Lardner's *Encyclopædia*, a typical product of the age.

To encourage the establishment of schools giving regular systematic instruction in science, the Science and Art Department offered attendance grants in 1872 to those institutes which adopted schemes set forth in the *Science and Art Directory*. In this way arose the *Organized Science Schools* (see page 115) which did much to establish the traditional methods of science teaching in this country.

25. *The Royal School of Mines*

The Royal School of Mines was the outcome of the geological survey of the early 19th century. A prominent member, Henry de la Beche (1796–1855) obtained permission to exhibit his large collection of geological specimens in two houses in Craigs Court, Charing Cross, which were allotted to him by the government. He afterwards established a chemical laboratory in connection with this museum. The geological survey became an important government department and de la Beche urged that a permanent museum might be founded. A site was obtained in Jermyn Street and in 1851 the Museum of Practical Geology was opened by the Prince Consort.[1]

[1] A pleasantly written account of the early history of the School of Mines, together with biographical sketches of the early lecturers, is to be found in M. Reeks. *History of the Royal School of Mines*. London, 1920.

At this time an enquiry into the state of the great coal mines and the causes of accidents, was in progress. Faraday, from the Royal Institution, and Lyon Playfair (1818–1898), a young chemist who had worked at the Craigs Court Museum, were Government Commissioners. Their investigations showed that there was much waste of time and money in the working of the mines, and that sheer ignorance often led to loss of life. The findings of the commissioners pointed to the need for organized science teaching in connection with the mines, so that a department of the Jermyn Street Museum was allotted for that purpose. The new department received the title *Government School of Mines and of Science Applied to the Arts.* It was opened in 1851, the year of the Great Exhibition. The first President was de la Beche, while Lyon Playfair lectured on Chemistry applied to the Arts, and Edward Forbes (1815–1854) on Natural History applied to the Arts. Robert Hunt (1807–1887) lectured on Mechanical Science, Andrew Crombie Ramsay (1814–1891) on Geology. In 1854 Huxley succeeded Forbes.

The School of Mines began its career with a distinguished staff, but with very few students. The necessity for a knowledge of science in mining and other industries was being preached on all sides, but students did not hurry to enrol themselves. During the first session there were only seven *bona fide* matriculated students who entered definitely for a two years course of study. Occasional students brought the average number attending the lectures up to 36. A diploma was given to students who passed an examination set by the school. It was originally intended that the students should be trained specifically for metallurgy

and mining, but gradually students availed themselves of the courses for the sake of a general training in science.

Some years previously, in 1845, a group of men interested in science, with Sir James Clark (1788–1870), physician to the Queen, at their head, had founded a College of Chemistry in Oxford Street The Prince Consort took a kindly interest in all schemes for the spread of scientific knowledge, and the institution became known as the Royal College of Chemistry. It consisted mainly of laboratories for the teaching of chemical analysis. The founders secured the services of Hofmann (1818–1892) of the university of Bonn, as first professor. The Royal College of Chemistry, being a private enterprise, was soon involved in financial difficulties. Higher education rarely pays its way. Ultimately the council of the college appealed to the government for assistance, and in 1853 the college was taken over and affiliated to the Government School of Mines.

The Science and Art Department thereupon introduced certain changes in order to give a system of technical instruction. The name of the School was then changed to *The Metropolitan School of Science applied to Mining and the Arts.* This pompous and uneuphonious title was much disliked, and the old name was resumed, and an added dignity was acquired in 1863 when the title became *The Royal School of Mines.*

As time went on more students found their way to the classes in Jermyn Street, and the accommodation proved quite inadequate. Huxley, on his appointment in 1854, entered with characteristic pugnacity and energy into a campaign on behalf of Natural History. He found himself in too great proximity to his colleagues in a

literal as well as in a metaphorical sense. His authoritative manner and skill in blackboard drawing made him a most impressive and effective lecturer. His scientific eminence made it an especial trial to him to be compelled to limit his teaching to lecturing and demonstration. He had no accommodation for any practical instruction. Moreover, under Hunt, Stokes and Tyndall, the department of Physics was in similar straits. The staff, under the leadership of Huxley, were loud in urging the necessity for a properly equipped college. The Royal College of Chemistry in Oxford Street also became uncomfortably crowded. The distinguished band of young chemists, including W. H. Perkin and H. E. Armstrong, who had gathered round Hofmann, had to work in two small laboratories along with many junior students.

Now the Prince Consort had long cherished the plan of establishing a great centre for scientific instruction at South Kensington. In 1868 there was a Government Commission with the reference "Could the School of Mines be made the foundation for a great technical school." Two years later a Royal Commission was appointed to enquire into "Scientific Instruction and the Advancement of Science." As a result of its report the Department of Chemistry, Physics and Biology were removed in 1872 from Jermyn Street to a new building in South Kensington. Afterwards the departments of Applied Mechanics, Metallurgy and Geology were also transferred to South Kensington.

Although officially the School of Mines gave instruction in applied science, yet the lecturers usually sought to give a wide interpretation in the teaching of their respective subjects, and in this way many school science

teachers received their early training under inspiring leadership.

In 1869 regular courses of lectures were given and vacation courses arranged for science teachers from the provinces. Mr. H. G. Wells has given us a delightful picture of the diligent student busy collecting science certificates, in *Love and Mr. Lewisham.* The valiant hero worked full time and even contrived to support a wife on his small government grant! The methods adopted by the government to encourage the teaching of science reveal the characteristic attitude of caution. Teachers from the provinces had certain concessions made to them. We read that:

> "Teachers who have taught two years consecutively and passed no less than 30 students each year are allowed 2nd class railway fare and £3 towards expenses while living in London (provided they remain there at least 5 days) for the purpose of visiting South Kensington and other metropolitan institutions, in order that they may acquire a knowledge of the latest progress of those educational subjects which affect the schools." [1]

The vacation courses given during the summer months consisted of:

(1) Laboratory instruction in the chemical Laboratory of the Royal College of Chemistry.
(2) A course of six lectures on the teaching of chemistry by Dr. Frankland.
(3) A course on the teaching of experimental physics by Dr. Guthrie.

[1] Report of Science and Art Department. 1870.

The Teachers who took the course in laboratory instruction were provided with a set of apparatus devised by a kindly government committee. The selection of teachers privileged to attend the course was determined by a competition held in the previous May. The lucky ones received 2nd class railway fare and 30s. per week while in London. The summer courses were a great improvement on the old examinations for teachers. Moreover when the School of Mines was reorganized by Huxley, who emphasized the importance of laboratory instruction, the teaching given must have been very valuable.

Later on the curriculum of the Royal School of Mines far outstepped the original schemes. In 1881 the added departments were grouped together under the name *The Normal School of Science.* In 1890 this name was changed to the *Royal College of Science* and it became incorporated with the Royal School of Mines.

26. *The University of London*

The first decades of the 19th century mark the opening of a new era in English social history. The results of the industrial revolution were now apparent. The Napoleonic Wars had left a burden of National Debt. The aftermath of the war gave rise to a more serious attitude and to an increased demand for university education. The expense of residence at Oxford and Cambridge and the religious tests were insuperable barriers to many. Once again a project was launched for a University of London. The suggestion was first

brought to the notice of the public by Thomas Campbell, the poet.[1]

A site in Gower Street was obtained and in 1827 the "University of London" was opened with 300 students. It had no charter and consequently no official status whatever. It was a proprietary institution, the funds being raised by shares, subscriptions and fees. It offered a wide curriculum and lectures were given by distinguished scholars. The fees were low and thus a high standard of education was available for the student of limited means. The governors avoided the difficulties of the religious question by excluding such teaching altogether. This raised a storm of criticism from zealous adherents of the Church of England, and a rival institution, King's College, was erected in the Strand. In 1836 a charter was given to a Federal University consisting of University College and King's College. In these days it is difficult for us to realize the intensity of feeling evoked by religious questions during the early history of the University of London. The "godless institution in Gower Street" avowed complete religious neutrality. It was, therefore, necessary for the committee responsible for the appointment of professors to exercise extreme caution in case their actions should be interpreted as favouring any particular religious body. The great mathematician Augustus de Morgan (1806–1871) resigned his Chair after more than 30 years service because he considered that the Council of University College rejected a candidate on the grounds of his religious belief. The account of the troubled life of de Morgan[2] gives us

[1] In a letter to the *Times*. February 9th, 1825.
[2] *Memoirs of Augustus de Morgan* by his wife. London, 1882.

some insight into the bitter wars of opinion which raged during the 19th century.

In 1850 a new charter was given to the university, and candidates were admitted for a degree from affiliated colleges in various parts of the country. This arrangement proved unsatisfactory and in 1858 degrees were awarded solely on the results of examination. While a high and rigid standard of attainment was demanded, the fact that there were no requirements as to residence led outside observers to regard the new university merely as a vast examining machine. But University and King's Colleges were nevertheless giving teaching of a very high standard and both colleges became centres for research. For example, Thomas Graham (1805–1869) came from the Andersonian University, Glasgow, to be professor of Chemistry at University College, London, in 1837. William Sharpey (1802–1880) was appointed to the Chair of Anatomy at University College in 1836. He taught there for nearly forty years. He was the first to give specific lectures on physiology, a subject hitherto regarded merely as an adjunct to medical studies. Alexander Williamson (1824–1904) became Professor of Practical Chemistry in 1849, and in 1855 combined the office with that of Professor of General Chemistry on the resignation of Thomas Graham and continued for more than 30 years. Williamson's investigations on etherification were among the earliest researches sponsored by the university. Graham's work as an original investigator was already recognized when he was called to University College. During his tenure of office, however, he continued his researches on the density of gases and their velocity of diffusion and carried out important work on osmosis and the properties

of colloids. At King's College, Wheatstone (1802–1875) became professor of experimental physics in 1844, and there carried out his researches on telegraphy and on the measurement of resistance and electromotive force. These examples are sufficient to show that the teaching of natural science was well established at both colleges before 1860, in which year the university created the Faculty of Science and conferred the degrees of Bachelor and Doctor of Science for the first time in this country.

27. *Provincial Universities*

Of the other newer institutions of university rank we must mention first the *Owens College*, Manchester, founded as a result of the bequest of John Owens. The college was opened in 1851 and incorporated in 1871. There was a marked scientific tradition in Manchester which had been upheld by the Literary and Philosophical Society and by the dignity of such great names as Dalton and Joule. In 1880 a charter was granted to *Victoria University*, which consisted at first of Owens College only. Four years later University College, Liverpool, was admitted, and in 1887 Yorkshire College, Leeds, was also included. From the first, the Victoria University granted degrees in science. Balfour Stewart (1828–1887) became professor of Natural Philosophy in 1870, and among his early pupils were Poynting (1852–1914), Sir J. J. Thomson and Sir Arthur Schuster. The theoretical investigations of Balfour Stewart on radiation, apart from their intrinsic importance, brought the problem of spectrum analysis before the gaze of the

scientific world, and thus inspired the subsequent work of Crookes, Liveing, Dewar and Lord Rayleigh.

Among the first professors at Manchester was Edward Frankland (1825–1899) whose researches in organic chemistry and investigations of the laws of chemical combination have been of such fundamental importance in the development of the subject. Frankland afterwards lectured at the Royal Institution and the School of Mines. His successor at Manchester was Henry Roscoe, who held the chair from 1882 to 1915, and who was a graduate in Arts of London. He came under the influence of Graham and Williamson in London and studied chemistry in Germany under Bunsen. Roscoe was an inspiring teacher and important investigations were carried out at Owens College under his direction.

In many cases the provincial universities have developed from university colleges where the students at first were prepared for London degrees. University College, Bristol, was opened in 1878, and Sir William Ramsay (1852–1916) became Principal in 1881 and held office for several years before coming to London as professor of Chemistry. In 1880 Mason College, Birmingham, was established, and twenty years later it achieved University rank, and Sir Oliver Lodge, who had been first professor of physics at University College, Liverpool, became the Principal. The few names of men of science we have mentioned indicate that the newer universities soon played an important part in the scientific output of this country.

Chapter VI

Nineteenth Century Secondary Schools

28. *The Beginnings of Science Teaching in the Public Schools*

AT the beginning of the 19th century there was no science teaching at the great schools. The curriculum at Eton under Dr. Keate typifies the practice of the time. The subjects of study were limited to the classics with a little divinity and such half holiday extras as Mathematics and French.[1]

During the first half of the century there were a number of new foundations of public school rank. Among these were Mill Hill (1807), King's College School (1829), University College School (1830), Cheltenham College (1841), Marlborough (1843), Rossall (1844), Wellington (1853) and Clifton (1862). They were untrammelled by outworn statutes and traditions and began by providing a more modern type of curriculum. Thus at Mill Hill in 1821 modern languages were taught and natural and experimental philosophy.[2] Indeed Mill Hill perpetuated the Nonconformist tradition by providing a wide curriculum and allowing scope for individual effort. Cheltenham College was organized with a modern side from the first, with mathematics as the main study, together with modern languages and physical

[1] H. Maxwell Lyte. *History of Eton College*. London, 1875, pp. 315, 364.
[2] Brett James. *History of Mill Hill School*. pp. 56, 66.

science.[1] The influence of these newer schools and the systematization of the classical curriculum due to the great head masters, Butler (1774–1839) of Shrewsbury, Arnold (1795–1842) of Rugby, and Thring (1821–1887) of Uppingham, introduced a scientific outlook into the study of language and thus to some extent helped forward the introduction of science teaching. But many difficulties had to be overcome before the importance of science received general recognition.

Science teaching was introduced in a tentative way at Rugby as early as 1849. A physician in the town gave lectures at the Town Hall and boys who wished were allowed to attend. When Dr. Temple became head master, science lectures were given by one of the mathematical staff. In 1859 a laboratory and lecture room were built and the teaching included botany, chemistry, physics, and geology. At this time a boy on entering the school had to choose between science and modern languages.[2]

Science lectures were given at the City of London School by Thomas Hall at about the same time. Although there were no facilities at first for experimental work by the boys, yet many were encouraged to carry out simple manipulations at home. It is interesting to note that W. H. Perkin was led to take up chemistry through the inspiration of Thomas Hall. Hall's successor at the City of London School, Henry Durham, was a vigorous champion of practical science teaching. For him, the subject was no soft optional nor was it limited to "qualitative analysis and the use of the blow pipe." His schemes show that he was alive to the importance

[1] *Schools Inquiry Commission.* Vol. IV, Part I, pp. 527 and 545–7.
[2] *Sixth Report of Royal Commission on Scientific Instruction.* 1875, p. 107.

of applied science and his pupils had to pursue a rigorous course.

29. *The Public Schools Commission* (1861–1864) *and the Schools Inquiry Commission* (1864–1868)

The Reports of the Royal Commissions of the sixties not only give us information as to the existing curricula but shed some light on contemporary views. We must confine ourselves to the parts of the reports which deal with science teaching. Apparently the Commissioners were first struck by the neglect of science in the great schools. They found that even in those Public and Endowed Schools where science had been introduced, the time spent was in most cases wholly inadequate. They found that out of 128 schools examined only 18 devoted as much as four hours a week to science while many gave no regular time whatever to the subject. Only 13 of the schools were found to have room set apart for practical work. The commissioners went so far as to say that natural science was practically excluded from the education of the higher classes in England.[1]

The arguments for the teaching of science were summarized in the report as follows:

> "It quickens and cultivates directly the faculty of observation, which in very many persons lies almost dormant through life, the power of accurate and rapid generalization, and the mental habit of

[1] *Report of the Schools Inquiry Commission.* 1864–1868. Vol. I, pp. 337, 435.

method and arrangement; it accustoms young persons to trace the sequence of cause and effect; it familiarizes them with a kind of reasoning which interests them, and which they can promptly comprehend; and it is perhaps the best corrective for that indolence which is the vice of half-wakened minds, and which shrinks from any exertion that is not, like an effort of memory, merely mechanical."

Yet the commissioners, though urging the importance of natural science, still regarded classics as the principal study. Their recommendations were based on the regulations for the teaching of *Naturkunde* in the Prussian Gymnasia. The commissioners thus suggested that one hour per week should be devoted to natural science, and that two main branches of science should be studied.[1] They certainly expected much to be done in this short time. They desired all boys to have some acquaintance with science and they deprecated the system of dividing a school into Classical and Modern Sides.[2]

It is of interest to note that while the deliberations of the Royal Commissions were in progress, experimental science teaching was being urged by Thring at Uppingham. Some natural science was also taught at the private schools. Thomas Arnold describes the commercial schools where the sons of farmers and tradesmen received their education. He tells us that "The rudiments of physical science are also taught in them and with a view to his particular business in life (the pupil) learns land surveying, if he is to be brought

[1] Public Schools Commission, *Report*, pp. 11–18, 28–33.
[2] *ibid.*, pp. 37–39.

up to agricultural pursuits, or book-keeping, if he is intended for a trade." [1]

At this time there were good as well as bad types of private schools in the country. The reports of the *Schools Inquiry Commission* (1868) show that many private schools for older pupils gave only rudimentary instruction and that they were organized solely on a profit-making basis. Other private schools gave advanced instruction and were often conducted by men keenly interested in educational experiments and ready to risk a financial loss.[2] Indeed Sir Joshua Fitch in an interesting report pointed out that in Yorkshire almost all the educational enterprises had originated with private teachers.[3] It is pleasant to reflect that the boarding schools of the sixties were not all like Dotheboys Hall.

30. *The Royal Commission on Scientific Instruction and the Advancement of Science*

A complete survey of contemporary science teaching of all grades is to be found in the monumental reports of the Royal Commission which sat from 1871 to 1875. This is usually referred to as the Devonshire Commission, its chairman being the seventh Duke. In the list of commissioners we find such great names as Stokes, Huxley, Kay-Shuttleworth and Lubbock. The Sixth Report [4] deals with secondary schools, and the evidence of the

[1] Thomas Arnold, *Miscellaneous Works*. London, 1845, p. 231.

[2] *Plans for the government and liberal education of boys in large numbers as practised at Hazlewood School.* (1822.)

[3] *Schools Inquiry Commission.* Vol. IX, pp. 534–601.

[4] *Sixth Report of the Royal Commission on Scientific Instruction.* C. 1279. 1875.

many witnesses, as well as the official recommendations, have an important bearing on our present study.

Since Rugby was the first great school to introduce science teaching, the commissioners attached considerable importance to the views expressed by the science master, the Rev. J. M. Wilson, afterwards Canon of Worcester. In a paper dealing with the teaching of geology and botany as part of a liberal education, Wilson claimed that science should form part of the general education of all young boys.

> "An orrery and globe, and a little astronomy, form the natural beginning. Let the boys make the effort involved in realizing the plan of our solar system, and our earth in space with its atmosphere mantling round it; its kinship to the planets, its relations to sun and moon. These, and some of the common phenomena—day and night, summer and winter, eclipses, and the changes of the moon—form the natural and the old well-established introduction to science. They are still subjects of surpassing interest to every successive generation. They take boys on all their sides—memory, imagination, and reason. They show, as nothing else shows, the connexion of cause and consequence. And there is a genuine and deep satisfaction, a real pleasure of the intellect, which boys attain when they first understand the causes of these common great phenomena. They stand thenceforward on a higher platform. The universe presents to them not a mere wonderland but a reign of law. These are the *literæ divinæ* written in the universe by the finger of God." [1]

[1] *Educational Times*. April, 1872.

The Report begins with a full discussion of the difficulties attending the introduction of science teaching into schools. We read that in many cases the expense of building suitable laboratories and increasing the staff was sufficient to deter the governing bodies from taking any steps towards encouraging science. The existing curriculum in many schools was considered overcrowded, and head masters were therefore reluctant to introduce fresh studies. Moreover the governing bodies and the head masters had been brought up on the classical tradition. Thus even if not definitely prejudiced against science and its implications they were at least doubtful of its educational value.

Now the question of the educational value of certain studies is one upon which schoolmasters and laymen have always felt qualified to give an opinion. Fierce controversies have raged round the question of the superiority of a classical over a scientific curriculum as a means of mental training, and the partisans of both sides have entrenched themselves behind the barriers of unverifiable opinion. Moreover the battles between the theologians and the men of science had left their mark. Head masters were inclined to look on science as having merely utilitarian value. They felt that the study of science was a cold-blooded intellectual feat having no beneficent effect on the character. Like Carlyle, they thought the progress of science was destroying the mystery of the universe. Like Blake, they felt it was making the rainbow cold.

Gradually, however, head masters had to face the fact that science had come to stay. In the closing decades of the century, the smaller grammar schools came into line with the great schools, built laboratories

and appointed science masters. One recalls the story of a reverend head master who, against his conscientious convictions, permitted chemistry to be taught in his school, and who, in order to encourage the subject, used to walk into the laboratory daily and tap the thermometer to see if it was going up or down!

At the time when the report of the Devonshire Commission was issued there were other obstacles blocking the way of science in the great schools. There were few masters qualified to teach the subject. Science had only just attained an acknowledged position in the older universities. Such men as were available had, in many cases, taken the examinations of the Science and Art Department or of the University of London. Men so qualified were usually of different social standing from the regular staff of the public schools. Consequently, in the rare cases when a science specialist was appointed he had an uncomfortable time in the Common Room.

The Devonshire Commissioners held that the value of science teaching consists not merely in the imparting of certain important facts, but in habituating the pupil to observe and reason for himself and to check his conclusions by further observations. They went so far as to suggest that the study of science, more than any other subject of the curriculum, offers tremendous scope for the "development and training of the mental faculties." They urged that since elementary science is no more difficult than elementary arithmetic and far more interesting to the young, it should be introduced early.[1]

Opinions as to the stage for introducing science

[1] *Sixth Report of Royal Commission.* 1875, p. 6.

teaching were obtained from Faraday, William Thomson, Ramsay of the Museum of Practical Geology, and from teachers in Mechanics Institutes and evening schools. The commissioners concluded from the evidence that elementary science teaching might be given from the beginning of the school career, that is, at the age of eleven or twelve years.

The plea of the overcrowded curriculum was apparently just as insistent in 1870 as at the present time. The report suggests, however, that since the number of hours of study in Public Schools may be taken at not less than 35 per week, if six be devoted to science, and six hours to mathematics, there would still remain at least 23 for the study of language and other subjects. The Commissioners even express the opinion that the influence of teaching in science might develop the pupil's powers to such an extent that his success in classics would be enhanced.

The evidence as to the effect of science teaching on the intellectual life of the school is summarized as follows in the 1875 Report :—

From Mr. Madan, the Science Master at Eton—

"Science work has, no doubt, brought out some boys who have previously shown no interest in, or power over, their school studies. Generally speaking, however, the best boys in classics are the best also in natural science."

From the Rev. Edward Hale, Assistant Master at Eton—

"Intellectual activity is promoted, and habits

of thought and observation are gained. Proofs of this are, that boys not remarkable for proficiency or the interest they take in their usual studies, are sometimes full of interest in learning science, and in rarer instances, enthusiastic."

From Rev. Thomas Dalton, Assistant Master at Eton—

"Almost all boys have had a certain amount of interest excited in them for this branch of knowledge; in several cases boys who have shown no aptitude for classics or mathematics have done extremely well in, and really worked at, physical science; but, as a rule, boys who are good in classics or mathematics, are good also in science."

From the Rev. J. M. Wilson of Rugby—

"The school as a whole is the better for it, and though pursued often with great vigour by boys distinguished in classics, it is not found to interfere with their proficiency in classics, nor are there any symptoms of overwork in the school. This is the testimony of classical masters by no means specially favourable to science, who are in a position which enables them to judge. The introduction of science into our course has been the greatest possible gain; and others who have left from the upper part of the school, without hope of distinguishing themselves in classics or mathematics, have adopted science as their study at the Universities. It is believed that no master in Rugby School would wish to give up Natural Science and recur to the old curriculum."

From the Head Master of Winchester College—

"I think there has been an interest created in botany and geology, which has altered the feeling of contempt for such things which used to be general. I do not think it affects the other studies of the school either way. The principal result is a more general spread of sensible estimates of the value of such knowledge."

From the Head Master of Wellington College—

"I introduced it into the classical sixth solely with the view of increasing the boys' interest in life (there is not enough to produce results in external examinations) and of improving their literary work by widening their interests. I think it succeeds in both respects."

From the Head Master of Manchester Grammar School—

"Since the introduction of the science teaching and the connected changes in our system, the number of our boys has largely increased. By the side of the old classical forms, which remain at least as strong as before, there have grown up science and mathematical forms, training for a life of study and a University career, boys who earlier would with difficulty have found a place for their special aptitudes. The number of prizes and certificates from South Kensington shows that an influence for good has been at work upon the younger boys, and to name the result which (to the schoolmaster) is, perhaps, the most important of all, the number of

utterly listless boys between 15 and 18, who seem incapable of being roused to take an interest in anything, has almost disappeared."

From the Rev. F. W. Farrar of Marlborough—

"There are two good results which it is producing now, and will produce more and more. 1. It enlarges the range of knowledge and intelligent interests for a large number of boys. 2. It has succeeded in stimulating and evoking the powers of a few boys who had failed completely in other studies. These results alone are amply sufficient to justify its introduction, and encourage us to persevere." [1]

A perusal of the mass of evidence given in the appendices to the report shows that there was some unwillingness on the part of parents to allow boys to devote time to science since it did not serve as an introduction to any definite profession. The utilitarian aspect of science in connection with "inferior" trades and manufactures seems to have blinded the parents to its cultural value, whatever may be included under that vague term. Many head masters were of the opinion that the universities could help forward the cause of science in the schools by offering more scholarships in that subject and by sending out good teachers.[2]

The main recommendations of the report were as follows:—

"On a review of the present state of the Public and Endowed Schools, it appears to us that no

[1] *Sixth Report of Royal Commission*, p. 55.
[2] *ibid.*, p. 60.

adequate effort has been made to supply the deficiency of Scientific Instruction pointed out by the Commissioners of 1861 and 1864. We are compelled, therefore, to record our opinion that the Present State of Scientific Instruction in our Schools is extremely unsatisfactory. We cannot but regard its almost total exclusion from the training of the upper and middle classes as little less than a national misfortune.

"We desire to express our own opinion that Scientific Instruction ought to commence from the beginning of the school career.

"We therefore recommend,

1. That in all Public and Endowed Schools not less than six hours a week on the average should be appropriated for the purpose.
2. That in all General School Examinations not less than one-sixth of the marks be allotted to Natural Science.
3. That in any Leaving Examination the same proportion be maintained." [1]

31. *The Influence of External Examinations on the Place of Science in the Curriculum*

After 1850 the curriculum of many schools was largely determined by the requirements of the various examining bodies. We must therefore consider the question of examinations in some detail.

[1] *Sixth Report*, p. 10.

Public examinations are of a comparatively recent growth. Before 1849 there was no examination for candidates for commissions in the Army. The first competitive examination for the Indian Civil Service was held in 1855, and examinations for the Home Civil Service were instituted at about the same time. The legislation following the Royal Commissions on Oxford and Cambridge resulted in the founding of scholarships tenable by students at any college or hall or by unattached students and the endowing of exhibitions and prizes. This encouraged more serious study among the elder boys at the great schools. The Army and Civil Service examinations also reacted on the work in schools.

The College of Preceptors was founded in 1846 "for the purpose of promoting sound learning and of advancing the interest of education."[1] Examinations for teachers and pupils were established and these provided a standard for the work of many private schools. The College of Preceptors certainly performed a useful service to education in the early years of its foundation. But still more important were the Oxford Local Examinations instituted in 1857, and the Cambridge Local Examination first held in 1858. The examinations were introduced to meet the needs of what were then called middle class schools. But on the recommendation of the Schools Inquiry Commission of 1868, the endowed schools also availed themselves of the advantage offered by such external tests. As a result of the Head Masters' Conference of 1870, the *Joint Board* or *Oxford and Cambridge Schools Examination Board* was established in 1873 to act as an examining body to those schools

[1] *Report of the Consultative Committee on Examinations in Secondary Schools* Cd. 6004, 1911, pp. 9, 43, 66.

which sent large numbers of boys to the universities. In the later decades of the century the matriculation examinations of London University became used as a leaving examination in schools by many pupils who had no intention of proceeding to a university course.[1]

At this time the preparation of boys for examinations in science was carried out by means of lectures and the reading of text books. Even in those schools provided with a special laboratory, practical work was regarded as a privilege and reserved for the advanced pupils. At Taunton, for example, the first two years of the science course were spent in studying mechanics from text books, and the pupils took the Oxford Local Examination in that subject. The third year was devoted to Chemistry lectures and demonstrations by the master, and in the fourth year the boys were allowed to perform certain manipulations for themselves. At the end of this year the pupils took the London Matriculation Examination.[2]

The preparation of pupils for examinations set a premium upon a knowledge of scientific facts as distinct from fundamental principles. Calculations which the examiners could quickly assess as right or wrong predominated in the Physics papers. Inorganic Chemistry papers frequently consisted of questions demanding merely verbal accuracy and skill in remembering "catches." Such examinations did much to bring science into disrepute with the classical head masters; although it is open to question whether papers set in other subjects were any better.

[1] *Report of Consultative Committee.* Cd. 6004, 1911, p. 390.
[2] Rev. W. Tuckwell, *The Method of Teaching Physical Science in Schools.* Paper read before the British Association at Exeter, August, 1869.

The matriculation examination of London University has exerted an enormous influence for good and perhaps for evil on the curriculum of schools. At the foundation of the University as an examining body in 1838, there was a pass and honours examination for matriculation, and lists of successful candidates were published showing their order of merit in the several subjects of the examination. In 1840 69 candidates passed and seven obtained honours.[1] During the nineties the number of successful candidates averaged over 2,000 per year. During recent years the numbers have been well over 8,000 per year.

The University was severe in its demands and consequently London degrees were held in high esteem. Originally Greek was compulsory for the matriculation examination. The other requirements consisted of Latin, Mathematics, English History and modern Geography, two branches of Natural Science and either French or German. Such a wide range of subjects meant that specialization came late. Whatever objections may be urged against the regulations of those days, at least some good must have resulted from the fact that the future classical scholar had some acquaintance with science and the embryo science student had some grounding in the classical languages.

The changes of the regulations for matriculation are of interest. In 1888 the requirements for matriculation were :—

1. Latin.
2. One language. Greek, French, German, etc.

[1] *Examination for Matriculation in the year* 1840. London, 1840, pp. 55–58.

3. English language with English History and Geography.
4. Mathematics.
5. Mechanics and Hydrostatics.
6. One of the following branches of experimental science. Chemistry, Heat and Light, Magnetism and Electricity.

For the year 1889–90, Botany was added to (6).

From 1890 to 1898 there was no further change in the regulations. In 1899 the requirements were :—

1. Latin—two papers.
2. English—two papers.
3. Mathematics—two papers.
4. General elementary science—two papers.
5. Any *one* of following languages or sciences—Greek, French, German, etc. Elementary Mechanics, Elementary Chemistry, Elementary Heat and Light, Elementary Electricity and Magnetism, Elementary Botany—1 paper.

The compulsory papers in general elementary science consisted of questions on simple statics, dynamics and hydrostatics, heat, light and chemistry. The regulations required that "the subjects shall be treated wherever possible from an experimental point of view."[1]

Thus at the end of the 19th century some knowledge of chemistry and physics was required of all London

[1] *London University Calendar*, 1898–99, p. 5.

matriculation candidates.[1] By this time the number of schools had increased considerably and more and more students were taking London degrees.

32. *The Royal Commission* (1895) *and the Board of Education Act*, 1899

The searching enquiries of the Devonshire Commission and its important recommendations forced the question of science teaching on the consideration of the governing bodies of schools. Consequently there was a growing demand for qualified science masters. The foundation of the Clarendon Laboratory at Oxford and the Cavendish Laboratory at Cambridge (see p. 129) mark the effective beginning of the modern science movement at the ancient universities. Science had always held a prominent place in the University of London and the provincial university colleges. Thus, during the last decades of the 19th century there were abundant opportunities for the training of the science specialist, and the future of science seemed bright indeed.

The second half of the 19th century witnessed the movement for the higher education of women. The movement began in 1843 with the Governesses' Benevolent Institution, which conducted examinations and awarded certificates to governesses. This led ultimately to the founding of Queen's College in 1848. Bedford College was founded in the same year. Two famous Girls' Schools were founded shortly afterwards,

[1] Since 1905, however, the demands of the matriculation examination have been relaxed and Latin and a Science are now alternatives.

The Ladies' College, Cheltenham (1853) and the North London Collegiate School (1850). The Schools Inquiry Commission considered the question of girls' education. Their reports on existing schools were not very favourable. In particular, the commissioners remarked on the lack of thoroughness in the teaching and on the superficiality of the exclusively feminine training in accomplishments. The development of the high schools from 1870 onwards was due to the growing recognition of the importance of girls' education. The new girls' schools availed themselves of the benefit of the local examinations of Oxford and Cambridge. For these schools, such examinations provided some standard of attainment which was of inestimable value in the early days of women's education. At the end of the century large numbers of girls' schools existed, and these were included in the enquiries of the Royal Commission of 1895. This Commission, usually known as the "Bryce Commission," dealt with the desirability of a State system of post-primary education. It reported that private endeavour, though excellent in many instances, had, however, failed to produce a sufficient number of schools. Moreover, the State was already subsidizing scientific education through the Science and Art Department and the Royal School of Mines, and it was felt that State aid should be extended to general post-primary education.

The term "secondary" was apparently borrowed from the French *école secondaire*. The expression came into general use in England during the second half of the 19th century, and was used in the report of the Royal Commission of 1895. The term was not defined, however, until 1902 (see p. 147).

The Commissioners of 1895 recommended the

formation of a General Education Department, with a Consultative Education Council. Into this council were to be merged the Charity Commission, the Science and Art Department and the existing Education Department. This new central authority was established by the *Board of Education Act* of 1899. It is interesting to note how the State approached the problem of secondary education from three paths, which afterwards converged into one. First the State was called in to pronounce on the Universities and on the education in the great endowed schools. Government aid had been invoked to promote the study of science and art, more particularly among the middle class students. Then when the problem of secondary education came up for discussion, the State had to probe into every department of education not included under the heading elementary. Thus, at the close of the 19th century, there was at last an organized department of secondary education. Although we pride ourselves on English individualism and encouragement of private endeavour, yet there was much confusion and inefficiency in secondary education in the 19th century, and it is generally conceded that the great developments of 20th century education have been largely due to the wise administration of the Board of Education.

Chapter VII

NINETEENTH CENTURY—ELEMENTARY EDUCATION AND TECHNICAL EDUCATION DIRECTLY UNDER STATE CONTROL

33. *The Establishment of a National System of Education*

AT the beginning of the 19th century there was no organized system of elementary education in the country. Many children never went to school at all, and it often happened that the children of the artisan class spent only two or three years at school. The charity schools of the 18th century still continued, but the teaching was of a very rudimentary character; indeed the authorities did not want the children to learn too much. At the time we are considering, the main work of such elementary education as existed was shared between two voluntary societies. The larger of these was the *National Society for Promoting the Education of the Poor in the Principles of the Established Church*, founded in 1811. The other organization was the *British and Foreign School Society*, so named in 1814. This society received support from the Nonconformists of the country.

In the early years of the 19th century, the problems of education were widely discussed. A small group of men, led by Bentham and Place, urged the establishment of schools for children up to the age of 14.

Bentham drew up an encyclopædic course of study under the name of the "Chrestomathic Scheme" but this did not materialize. The Reform Bill of 1832 brought up the question of education, for it was realized that an illiterate electorate would be a source of danger to the country. In 1833 Parliament voted £20,000 for the purposes of education. The money was administered through the two voluntary societies. A few years later the grant was increased to £30,000 per year. The amount was ludicrously small—in fact, Brougham pointed out that double that sum had been voted for the Royal stables.

The legislation of the succeeding years does not concern us here. Mention must be made, however, of the Royal Commission of 1858, under the Chairmanship of the Duke of Newcastle. The commission was appointed "to enquire into the present state of popular education in England, and to consider and report what measures, if any, are required for the extension of sound and cheap elementary instruction to all classes of the people." [1] The investigations disclosed a very unsatisfactory state of affairs. It was realized that something must be done to raise the standard of attainments and to ensure the attendance of the children. Such considerations led to Lowe's *Revised Code* of 1862, by which grants to schools, and hence the salaries of the staff, depended on the results of an individual examination of the pupils. This system of *payment by results* affected the whole system of elementary education for many years. The examinations consisted in specific tests in reading, writing and arithmetic in six gradations of difficulty, which became the well-known six standards.

[1] Hansard. *Parliamentary Debates*, Vol. CXL, p. 1955.

The merely instrumental subjects thus received undue emphasis. Attention was directed to bringing pupils up to a certain mean standard of attainment. Thus, the dull ones were urged on, but the clever were left alone. The teaching became monotonous and the whole atmosphere of the schools one of dead uniformity.

Attempts had been made to introduce some science teaching into the elementary schools at an early date, but there was no further development in such teaching because of the necessity of keeping the pupils up to a certain level of attainment in the prescribed subjects of the *Revised Code.* Moreover, the schools could not afford to introduce effective practical instruction which was expensive. The question of expense is never absent from the administration of public education. The following choice extract shows that any fears on the subject of expenditure on science were quite unfounded.

> "'Science', a term at which so many amongst us are unnecessarily scared, means . . . a knowledge of the simplest phenomena of everyday life. . . . The alarm of those who object to *science* as a subject of instruction will be quieted when they learn that last year only £177 14s. 10d. was the grant asked for on account of scientific apparatus in all our elementary schools together."[1]

The method of payment by results curtailed Government expenditure in education to some extent, and thus achieved one of the objects of the Revised Code. But the more far-seeing statesmen of the time realized that profound changes were necessary to secure

[1] A letter to the Rt. Hon. Robert Lowe, M.P., by the Principal of the Normal College, Cheltenham, 1861.

efficiency in the elementary school system. It was evident by this time that there must be more centralized administration and that the existing voluntary societies, though aided by government grants, could not deal effectively with the great problem of education. In 1870, under Gladstone's first ministry, a Government Bill was passed dealing with education. This resulted in the great *Education Act*, by which a local rate was to be levied and administrative authority vested in School Boards elected *ad hoc* in various districts.[1] Six years later education was rendered compulsory throughout the country.

34. *Introduction of Science into the Elementary School Curriculum*

The School Boards arranged the curriculum of the schools under their charge according to the Government Code in force at the time. Certain subjects were compulsory, others optional. The growth of public interest in education, due largely to the writings of Herbert Spencer and of Huxley, showed itself in the attempt to expand the curriculum. Thus in 1871 the Code provided a special grant for individual scholars who passed in two "specific" subjects in addition to the three R's. These subjects included "geography, grammar, algebra, geometry, natural philosophy, physical geography, the natural sciences, political economy, languages." The establishment of this "special" grant marks an important stage in the

[1] Hansard, CXCIX, p. 445; CCII, p. 280.

evolution of science teaching. The curriculum of elementary schools from 1875 to the closing years of the century consisted of three divisions.

1. The obligatory subjects, i.e. the three R's, together with needlework for girls.
2. The class subjects, which were optional for the whole school above Standard I.
3. The specific subjects which were taught to individual scholars in Standards IV to VI.[1]

The London School Board appointed a special committee to enquire into the curriculum of the schools. The leading spirit was Huxley. The report not only affected the London Schools but, by its insistence on high ideals for the elementary schools, had a marked influence on education throughout the whole country. The committee recommended that in Junior and Senior schools there should be given graded *object lessons*, embracing in the six school years a course of elementary instruction in Physical Science and serving as an introduction to the science examinations conducted by the Science and Art Department.[2]

As a result of the suggestion, object lessons were given by enthusiastic teachers, who endeavoured to show the relationship between scientific facts and problems of everyday life. Naturally in the early years of the Board Schools the large influx of pupils of varying ages, some with no groundwork of knowledge, rendered any systematic teaching of science an impossibility.

By 1878, however, the upper standards of the schools consisted of pupils who had been through the full

[1] Special Reports on Educational Subjects, 896–7, pp. 58–63.
[2] School Board for London. *Minutes*, 1871. Vol. I, pp. 155–159.

course. In that year, the London School Board, through the influence of the distinguished chemist, John Hall Gladstone (1827–1902), issued a syllabus of object lessons for the younger pupils and of elementary science for the optional subjects of the Whitehall Code and the more specialized subjects for the examinations of the Science and Art Department. As evidence of the relative popularity of the science subjects, we may note that in 1881 6,901 children took animal physiology, 411 took botany and 51 mechanics, the only other science subject offered.[1] The popularity of biological subjects was probably due to Huxley's excellent text books on physiology and physiography.

About this time Dr. Gladstone arranged that every school under the London Board should have the use of an inexpensive box of apparatus for experimental illustration in chemistry and physics. The Board appointed certain peripatetic Demonstrators, who went from school to school, to show the teachers how to use the apparatus contained in that little box.

In 1884 the School Board for London decided that the peripatetic plan of teaching mechanics be tried in some districts of London. The teaching of mechanics according to this plan was commenced the following year in twenty schools in the Hackney and Tower Hamlets Divisions. The science demonstrator gave a lesson fortnightly to the boys in the fifth and higher standards, the lessons being illustrated experimentally by specimens and apparatus carried from school to school. Between the visits of the demonstrator instruction was given to the same class by a teacher who was present at the demonstrator's lesson. The plan

[1] Final Report of the London School Board. London, 1904, p. 103.

worked well, so the Board two years later extended the system to other parts of London, and appointed three additional science demonstrators as an experiment for three years. The three demonstrators appointed were Mr. G. E. Blanche, Mr. A. Hubble and Mr. S. R. Todd.

So many head teachers took up mechanics as a subject in their schools, it was found necessary in 1890 to appoint two assistant science demonstrators. Eventually the staff was increased to four demonstrators and four assistants. Each science demonstrator conducted classes for teachers on the use of the apparatus employed in illustrating the teaching of the three stages of Mechanics. The favoured teachers selected to attend these classes were those who used to repeat the lessons given by the science demonstrators at their fortnightly visit.

Dr. Gladstone tells us [1] that the London School Board encouraged the teaching of simple natural history throughout the whole of the child's school life, simple books on science were introduced into school libraries, and the Board co-operated with the *National Health Society* in offering prizes to girls in physiology.

The teaching of science in the Board Schools at this time consisted in oral lessons and demonstrations by the instructor; Liverpool, for example, followed the example of London, by employing a science instructor and assistants. The instructor gave lessons at some 20 different schools during the week, and the requisite apparatus was trundled along on a hand barrow.[2] This

[1] *Report of the British Association for the Advancement of Science.* 1879, pp. 475–476.
[2] *ibid.*, p. 478.

arrangement certainly minimized expenditure on material things, and the children apparently received strictly equal shares of the things of the spirit. But we are sorry for the instructors.

In 1882 it was enacted in the Government code that "simple lessons on objects and on the phenomena of nature and common life, and appropriate and varied occupations [1]" were to be encouraged in Infant Schools, and "Elementary Science" was definitely prescribed as a class subject in senior schools.

At this time the question of science teaching was being discussed on all sides. A committee of the British Association dealt with the methods of teaching science in schools (see p. 142). The committee emphasized the importance of practical work by the pupils themselves to such an extent that teachers and school authorities began to feel that teaching by demonstration was of no value whatever.

The introduction of the heuristic method of science teaching (see p. 142) into elementary schools was not an easy matter. The lack of equipment and the difficulties of dealing with large numbers of children meant that the only effective teaching was by the discredited method of demonstration by the teachers. Cases are on record of brave enthusiasts who introduced heuristic teaching into the elementary schools. But the tendency in the later decades of the 19th century was for physical science to be replaced by nature study, which was supposed to lend itself to heuristic teaching without involving expensive apparatus or specially equipped rooms.

[1] Code Article 106 (*b*). 1882.

35. *Organized Science Schools and Evening Schools*

Certain of the Board Schools where science flourished presented their older pupils for the examinations of the Science and Art Department and so received grants from that body. In this way, these schools became what were called *Organized Science Schools*, a group first recognized by the Science and Art Department in 1872. These schools had grown up to meet the need for scientific instruction of a more advanced kind. They included not only "higher grade" elementary schools but also many private and grammar schools who had been tempted by the generous grants of the Science and Art Department to adopt a predominantly scientific curriculum. The Regulations required a school of science to give not less than thirteen hours a week to an obligatory course of not more than five hours mathematics and in addition chemistry, drawing and practical geometry. Of the remaining ten hours of the working week two might be given to manual work and two to mathematics or art. This left only six hours for English and other languages, history, geography and other general subjects. Such a course of study might well have been given to boys who had been through a general school course and who were specializing in science and then proceeding to a university. But unfortunately many much younger pupils were subjected to the same one-sided curriculum. Art could be omitted altogether, and the linguistic subjects received very scant attention. The only experimental science subjects were physics and chemistry, and the whole range of biological studies are not even mentioned in the scheme. The teaching

of science in the organized science schools was often highly efficient. The boys were familiar with much of the ground covered by such a large text book as Roscoe and Schorlemmer's *Treatise on Chemistry*. But the whole trend of the teaching was towards the acquisition of knowledge which could be readily reproduced on examination papers. In physics the subject usually consisted in the mastery of some text book on heat, light and sound, and occasionally on electricity and magnetism. We fear, too, that the laboratory work consisted merely of practical exercises and was not experimental in the real sense. There can be no doubt that in the days of the organized science schools the idea that elementary science consists of physics and chemistry became deeply rooted in the minds of teachers and school authorities. That notion still remains. No one would deny the intrinsic importance of these subjects, nor their value as a basis for the biology course. Nevertheless the academic teaching of chemistry and physics to young boys and girls involving, as it so often does, the total exclusion of biological topics is surely a grave error.

By the end of the 19th century considerable instruction in science came to be given also in evening schools. The earliest type of such schools were the "night schools" founded by the *Society for the Promotion of Christian Knowledge* early in the 18th Century. These night schools played an important part in the voluntary education which preceded the Act of 1870. After the passing of this Act the night schools became absorbed into the elementary education system and were consequently subject to the enactments of the Government Code. This meant that every pupil had to be examined

in the three R's, a state of affairs that was absurd in many cases. Authority for the omission of such examination was obtained through an Act entitled "An Act for the purpose of making operative certain Articles of the Education Code, 1890." One of the clauses of this Act allowed an evening school to be exempted from giving elementary instruction as defined in the great Education Act.

Legally the clause was limited to certain alterations in the Code of 1890. Nevertheless it was freely applied to future developments in evening schools, and the London School Board was particularly active in this direction. As a result a curious anomaly arose. The Board Schools were bound by the Code to give elementary instruction in the three R's but the optional subjects gave considerable scope for teaching of a more advanced character. The evening schools forged ahead and gave instruction in science, art and languages, and the various institutions receiving grants from the Science and Art Department were also giving instruction of a fairly advanced character. Meanwhile certain schools of art felt the rivalry of the free art schools of the London School Board. Now the governing body of one of these schools had been incorporated under the Companies Act and paid rates. This school, in its own interests and those of other Art schools and certain schools of science, set on foot those inquiries which ended in the famous "Cockerton Case." It transpired that Mr. Cockerton, District Auditor under the Local Government Board, disallowed certain expenditure of the London School Board. As a result of the case *Regina* v. *Cockerton* it was decided that a School Board, out of money raised by the rates, should not provide

instruction outside the Codes issued for public elementary schools.[1] The instruction of students in evening schools out of funds provided by the rates was also declared illegal. The decisions arising from the Cockerton judgment showed the need for stricter definitions of elementary and secondary education. Such definitions were given in subsequent Education Acts. It was not until the early years of the present century that post-primary education became systematized.

36. *Technical Education*

The trade depression of 1884–1886, together with the growing fear of foreign competition, created a feeling of alarm at the inadequacy of the technical education in this country. As usual a Royal Commission was appointed to inquire into the matter. The commissioners visited important centres of technical instruction on the continent and published their final report in 1884. They recommended an extension of manual, technical and scientific instruction in elementary and secondary schools.

In 1888 the *Local Government Act*[2] created County Councils and allotted to them an income out of the Probate and Licence Duties. The following year the *Technical Instruction Act*[3] was passed. This Act empowered the local authorities to aid or maintain technical education in their localities. This subsidizing of technical education was quite independent of the grants

[1] *Law Reports.* K.B.D. Vol. I, pp. 343, 733, 739.
[2] E. Jenks. *An Outline of English Local Government.* London, 1894.
[3] 52 and 53 Vict. c. 41.

of the Science and Art Department, and of the organization of science teaching under the School Boards which continued until the Cockerton judgment. In 1890 the *Local Taxation (Customs and Excise) Act* handed over a large sum from the Customs and Excise Duties to the local authorities for the purposes of technical education. This grant became known as "whisky money." The local authorities thus found themselves with money in their hands, and began to spend lavishly.

The term "technical education" was given a wide interpretation in the Act of 1889, being defined as instruction in the principles of science and art applicable to industries and including instruction in those branches of science and art recognized by the Science and Art Department.[1]

The local authorities were authorized to expend money on any or all of the three objects:

1. To *supply* technical education, i.e. work directly by founding schools, establishing classes and engaging teachers themselves (sec. 1(1), T.I. Act, 1889).
2. To *aid the supply* of technical education by making grants to governing bodies of schools and classes supplying technical education, under certain conditions (sec. 1. (1), d, e, f, T.I. Act, 1889).
3. To promote technical education by establishing *scholarships* and *exhibitions*, or paying fees of scholars, i.e. by making grants (on conditions) to individual students of merit, to enable them to obtain technical education at some school or class (sec. 1., T.I. Act, 1891).[2]

The London County Council began to face its new

[1] Technical Instruction Act, 1889, section 8.

[2] *Report to the Special Committee on Technical Education.* London, 1892, p. 7.

responsibilities by instituting a committee of inquiry into the whole of the technical education in existence in London. The Committee reported on every institution giving scientific teaching including University and King's Colleges, Secondary Schools, the Polytechnics, evening classes, and even the very rudimentary science teaching given in the Board Schools. The Committee then made suggestions as to how existing institutions might be helped by the Council and how far fresh fields of technical education might be opened out with the aid of the increased funds at the Council's disposal.

The sections of the report dealing specifically with science teaching are of particular interest in our present study. The Secretary of the Committee, Sir Hubert (then Mr.) Llewellyn Smith, had the advice of a number of experts including Wm. Ramsay, Ayrton, Rücker, Thorpe, Silvanus Thompson, Sir Philip Magnus and Dr. C. W. Kimmins.

The report stated that, with a few brilliant exceptions, effective practical work was entirely wanting in the schools. One of the London School Board demonstrators was trying to introduce "heuristic methods" into a group of Board Schools, but the practical work in secondary schools consisted almost entirely of qualitative chemical analysis, having no connection with chemistry taught in the class room. The Committee stated that practical physics was almost entirely absent. They blamed the South Kensington Examination and Oxford and Cambridge Local Examinations for this state of affairs.

With regard to the scientific training for trade apprentices, the Committee considered that the chief difficulty lay in the rooted disbelief in the value of such

training shown by the managers of chemical works and tanneries. Such lectures as were given to trade apprentices were found to be quite inadequate. The lectures given were on the lines of the traditional methods of the organized science schools and not in any way adapted to the conditions of industry. The teachers were not of high intellectual outlook and were severely overworked.

The report served as a guide to the London County Council during the early years of its work. The powers which the Council now possessed under the Act were delegated to the *Technical Education Board* appointed in 1893. Now the Act did not allow local authorities to spend money on literary education, so that they could not build secondary schools of their own. They did, however, offer scholarships and pay grants to Secondary Schools and to University Colleges and to other institutions towards the cost of the teaching of science, art, modern languages, commercial subjects and manual training. The grants thus forthcoming from the local authorities soon resulted in vast improvements in the equipment of science laboratories in schools and colleges. The scholarships aided students to study at the newer universities and university colleges. The grants enabled these institutions to enlarge the scope of their teaching. In this way better qualified science teachers were available for schools and technical institutes. Thus in the last decade of the 19th century, science, which has been so often neglected in the past, became the focus of interest. But the jurisdiction of the local councils began to overlap that of the School Boards and this prepared the way for the Education Acts of 1900 and 1902 when the local authorities took over the whole education—technical, secondary and elementary.

Chapter VIII

The Scientific Laboratory as a Means of Instruction

37. *The Establishment of the Modern Type of University Laboratory*

THE evolution of the university laboratory for the training of students has been a slow process. The "elaboratory," that is to say, workshop of the early experimenters, was often a cellar or kitchen. Even after Natural Science was recognized at Oxford and Cambridge and examinations instituted, a considerable time elapsed before adequate laboratories were provided, so that practical training could become part of the general course for students of science.

Of the great men of science of the first half of the 19th century, most received no training in experimental methods. Such was the case with Dalton, Young, Robert Brown, Darwin, Joule, Davy, Faraday. Young and Darwin were among the few who studied at a university. Darwin studied medicine for a time at Edinburgh, but he tells us that the lectures on anatomy and geology were such that he decided never to study these subjects again. Young spent but one session at Edinburgh as a medical student. Even in the 50's and 60's, a training in manipulative methods for students of physics was not considered necessary. The leaders of the school

of mathematical physicists of the 19th century, Green, Stokes, Kelvin and Clerk Maxwell, had no chance of doing experimental work while at Cambridge.

William Thomson, Lord Kelvin (1824–1907), followed the example of all the younger men of his day in obtaining an introduction to a leading man of science on the Continent with the hope of being allowed to assist in his experiments. Thomson was fortunate in being presented to Regnault, who was then investigating the density of gases.[1] Regnault's researches are still models of accurate experimentation, and Thomson could have found no better teacher. After a short apprenticeship under Regnault, Thomson was appointed to the Chair of Natural Philosophy at Glasgow. He found that the principles of Dynamics and of Electricity had been well taught by his predecessors but that the materials were quite inadequate. Such apparatus as existed was from fifty to a hundred years old and most of the woodwork was worm-eaten mahogany. There was no provision for experimental investigations by the professor, nor had any idea of practical work for students ever entered into the schemes.[2]

Students of chemistry and botany in those days were treated with somewhat more consideration. Thomas Charles Hope (1766–1844), who succeeded Black in the Chair of Chemistry at Edinburgh, encouraged his students to practice manipulative methods for themselves, and had regular classes in the earlier 20's. Thomas Thomson (1773–1852), professor of chemistry and mineralogy at Glasgow, established a laboratory for students about

[1] See S. P. Thompson. *Life of Lord Kelvin.* Vol. 1, p. 54 *et seq.*

[2] See Lord Kelvin's address to the University of Bangor, 1885, on *Nature*, Vol. XXXI, p. 409.

1830. Medical students also had a certain amount of experimental work in dissection as part of their training in anatomy. John Hughes Bennet (1812–1975) is said to be the first teacher of pathology to give systematic instruction in microscopical examination.

The close link between physics and pure and applied mathematics, and the fact that the same professor often lectured on all these subjects, was apt to lead to a neglect of the experimental side. The equipment of a physical laboratory for students' work has always required a larger initial expenditure than a laboratory for chemistry or botany. Consequently students of physics often had to be content with a few demonstrations by the professor who used time-honoured apparatus of solid construction. It was only on special occasions that the powerful Whimshurst machines and imposing air pumps were dusted and brought out from the obsecurity of their hiding places.

William Thomson at Glasgow was a pioneer in the organization of students' practical work in physics. The young professor persuaded the university authorities to make a preliminary grant of £100 for the purchase of instruments. This was followed by further minute sums, but the university council, with the caution said to be characteristic of their nation, appointed a committee to supervise the expenditure. Thomson soon began a number of important investigations, including some work conjointly with Joule, but found himself hampered by lack of equipment. He had no skilled assistants and very little room to move. However, he managed to acquire a disused cellar in the college basement and he organized a band of voluntary helpers from among his students. The old basement room in

which they worked was one of the first physical laboratories for students in any university. There was no special apparatus for students' use in this laboratory, not even such elementary contrivances as would to-day be found in every polytechnic, no laboratory course, no special hours for students to attend, no assistants to advise or explain, there was no mechanic's workshop, no marks were given for laboratory work, and no fee to be paid. But the few students who worked there had plenty of energy and enthusiasm. Indeed Kelvin's work at Glasgow was a source of inspiration for men of science for more than fifty years and marks an important period in the history of scientific education.

38. *The Development of Experimental Teaching in London and the Establishment of Practical Examinations*

Laboratory instruction for students was given an important place even during the early years of University College, London. Practical chemistry classes were organized by Edward Turner (1798–1837) in 1828. In the early 30's John Lindley (1799–1865) taught botany and his students learned the use of the microscope. He rode to college daily on his horse carrying armfuls of specimens. Turner was succeeded in 1837 by Thomas Graham (see p. 84) who had studied under Thomas Thomson at Glasgow and Hope at Edinburgh. University College has been indebted to Scotland for many of her distinguished professors. Graham held the Chair of Chemistry at the College for nearly twenty

years and was examiner in chemistry to the University of London for a considerable time. He was a staunch advocate of practical work for students and his own experimental researches brought fame to his department.

A Chair of Practical Chemistry had been created at the college and Alexander Williamson (see p. 84) succeeded George Fownes (1815–1849) in 1849. Williamson was a great teacher and shares with Graham the honour of having inspired high ideals of teaching and research at the college. As at other universities the experimental teaching of physics lagged behind that of the other sciences. Dionysius Lardner (1793–1859), that Lothario of science, lectured on natural philosophy at University College in the early 30's and merely illustrated his lectures with demonstrations. At that time the subject included astronomy, mechanics, hydrostatics, pneumatics and the mechanical theory of heat, and the joint subject mathematics and natural philosophy formed part of the ordinary Arts course.

An experimental and descriptive course in natural philosophy and astronomy was given from 1860 to 1865 by Richard Potter (1799–1866) the successor of Lardner. In 1865 G. Carey Foster (1835–1919) became professor of experimental physics and T. Archer Hirst (1830–1892) succeeded to the newly created Chair of Mathematical Physics. Carey Foster organized the teaching of practical physics and encouraged students to undertake original investigations. He instituted a workshop for the making of apparatus and mechanical models as well as for the usual laboratory repairs.

We must bear in mind that the English men of science who introduced laboratory instruction for students had usually studied on the Continent. It was in the German

universities that students' classes in practical chemistry were first successfully organized on a large scale. As Hofmann once said, "It was here (at Giessen) that experimental instruction such as now prevails in our laboratories received its earliest form and fashion; we are proud of the magnificent temples raised to chemical science in all our schools and universities—let it not be forgotten that they all owe their origin to the prototype set by Liebig." [1]

Claims for priority are of small importance. The outstanding fact remains that from about 1850 onwards teachers of science all over Europe were beginning to realize the need for the training of students in experimental methods. Although the need was recognized, yet it took some years for a system of experimental teaching to become organized at the two ancient universities of this country. Thus when Rayleigh (1842–1919) was at Cambridge he attended the lectures of Stokes on Optics and was impressed by the lecture demonstrations. Rayleigh wished, after he had become Senior Wrangler to remain and assist Stokes with his experiments, but we are told that he received no encouragement.[2] Rayleigh had no experimental training while at Cambridge so that he simply dabbled in chemistry and electricity on his own account. True, he took a course in qualitative analysis under Liveing. But this "test-tubing" as it was popularly called was certainly not the preparation that Rayleigh needed. The lack of instruction in laboratory work he said afterwards wasted three or four years of his life.

We have seen how the Royal College of Chemistry

[1] Quoted in an Article by Ira Remsen. *Nature.* Vol. 49, p. 287.
[2] *John William Strutt, Third Baron Rayleigh*, by his son. London, 1924.

was founded in 1845. Here systematic laboratory instruction formed part of the training for every student. Hofmann, the first professor, was an inspiring teacher and the students worked with the enthusiasm of pioneers. Here it was that W. H. Perkin (1838–1907) worked as Hofmann's assistant. Some chance comments of Hofmann induced Perkin, when a boy of seventeen, to try the preparation of certain organic substances during the vacation in the little laboratory he had fixed up at his home. His work resulted in the isolation of the first dye ever produced from coal tar, which became known as aniline purple or *mauve*. Perkin's discovery in 1856 was the beginning of the great dye industry.

An interesting account of the early days of the Royal College of Chemistry is given by a former student.[1] He tells us how the students used to enjoy the lectures of Tyndall and of Huxley in Jermyn Street. There was as yet no general course of laboratory instruction there. It was not until Huxley was installed in the new buildings at South Kensington that he was able to carry out his schemes for the experimental teaching of the biological sciences.[2]

King's College, London, was early in the field in the organization of practical physics. The researches of Wheatstone (see p. 85) attracted many students to the College, but he was not an inspiring teacher and seldom lectured. The teaching work was organized satisfactorily by the other lecturers. A description of each measurement to be made was given to every student and the work

[1] H. E. Armstrong, *Pre-Kensington History of the Royal College of Science and the University Problem.* London, 1921, p. 4.
[2] L. Huxley, *Life and Letters of Thomas Henry Huxley.* London, 1903. Vol. II, p. 82.

was periodically examined by the demonstrators.[1] Obvious as this arrangement may seem to us now, it was an advance on the haphazard methods by which students had previously worked.

In 1860 the authorities of Owen's College, Manchester, debated whether it was desirable to create a Professorship of Natural Philosophy in addition to that of Mathematics. Stokes and de Morgan were called in to give their advice. They urged that the work of the college necessitated the organization of experimental physics. As a result Robert Bellamy Clifton (1836–1921) was elected to the Chair of Natural Philosophy. In 1866, however, he accepted the Chair of Physics at Oxford and at once instituted experimental teaching.[2] He began with a small class in a room borrowed from the Anatomy Department. It was soon recognized that better accommodation was needed and the building of the Clarendon Laboratory was begun in 1868. Two years later classes were held there and the building was completed in 1872, forming part of the Oxford Museum.[3]

At this time there were no practical examinations in Physics for the Intermediate and Final B.Sc. or for the preliminary examinations for medical degrees. The London regulations were severely criticized on this account. It is sad to relate that the lack of practical[4] examinations frequently meant that the students did little experimental work although they had opportunities.

[1] W. G. Adams, *Nature*. Vol. III, 1871, p. 323.
[2] *Nature*. Vol. I, 1869, p. 26.
[3] *Nature*. Vol. III, pp. 14, 170, 192, and Ackland and Ruskin. *The Oxford Museum*. London, 1893.
[4] Physics at the University of London. *Nature*. Vol. X, 1874, pp. 506, 521.

Cambridge led the way in practical examinations and Oxford and London soon followed. In 1874 a simple laboratory test was introduced in the examination for the Natural Science Tripos. It consisted of a mixed paper containing questions on physics, chemistry and mineralogy. Three years later a simple oral test on the use of apparatus was given in connection with the paper in physics for the first M.B. examination. In 1889 a practical and viva voce test in chemistry was given at the London examinations.[1] In the same year a " viva voce interrogation on the use of instruments " was added to the Intermediate examination in physics and a definite practical test in physics given to all candidates for the Final B.Sc.[2]

The following extract from Sir Arthur Shipley's reminiscences shows that students of biology, even in the 70's, suffered from the lack of adequate laboratory instruction.

> " When I began to study Botany in 1879 at St. Bartholomew's Hospital, the only attempt at practical work was to hand flowers round in the lecture room, which we sometimes dissected but I am afraid more frequently threw at the lecturer. In the following year when I came up to Cambridge, apart from the medical school there were recently constructed laboratories for the teaching of zoology and physiology, but excepting the herbarium there was no laboratory for teaching botany . . . the Cavendish laboratory was then, as now, doing work which has made it the Mecca of all physicists

[1] University of London Calendar. 1888–89.
[2] *ibid*, 1890–91.

throughout the world. The Chemical laboratory was there also, but ill-housed and inconveniently arranged.[1]

We have already mentioned the establishment of the Natural Science Tripos at Cambridge in 1851. At that time lectures in anatomy, physics, botany, chemistry and applied mechanics were given in rooms that were inconvenient and badly arranged.[2] It was realized that as soon as more students presented themselves for this Tripos, better accommodation would have to be provided.[3] During the period 1863–1865, arrangements were made for the housing of the Departments of Zoology, Comparative Anatomy, Human Anatomy, Chemistry, Mineralogy and Botany.[4] Michael Foster (1836–1907), the pupil of Sharpey, came to Trinity College in 1870 as Praelector in Physiology. The modern period of biological research at Cambridge was the outcome of Foster's work. The University next turned its attention to the needs of the student of physics. This subject had now acquired a new prominence as it was included in the examination for honours of the Mathematical Tripos in 1868. A scheme was launched for providing lecture room, laboratory, and class rooms for the professor. The establishment of a Chair of Experimental Physics was rendered possible by the gift of the seventh Duke of Devonshire, Chancellor of the University.

[1] A. E. Munby. *Laboratories—Their Plannings and Fittings.* London, 1921. Introduction by Sir Arthur Shipley, p. xiii.

[2] R. Willis and J. W. Clark. *Architectural History of the University of Cambridge.* Cambridge, 1886, Vol. III, p. 180.

[3] *ibid.*, p. 137.

[4] *ibid.*, p. 181.

39. *The Cavendish Laboratory*

Clerk Maxwell (1831–1879) was elected as the first Cavendish Professor and delivered his inaugural address on October 25, 1871. By a Grace of the Senate, it was enacted that the principal duty of the professor should be to :—

> " teach and illustrate the laws of Heat, Electricity and Magnetism; to apply himself to the advancement of the knowledge of such subjects and to promote their study in the University."

For some time after his appointment Maxwell had to devote his whole attention to the building and equipment of the Cavendish Laboratory. He threw himself with characteristic energy into his new work. In dealing with students the influence of his great personality must have been incalculable, and for those able to follow his rapid changes of thought his lectures must have been a source of inspiration and delight.

Before 1870, in spite of great achievements, there was a lack of systematization of physical ideas, whereas the mathematical superstructure was an imposing edifice. There can be no doubt that so long as mathematics and natural philosophy were in the hands of one teacher, it was really the natural philosophy that suffered. In dealing with immature students it is well to be definite where possible, so that it is not surprising that the professor of the joint subjects natural philosophy and mathematics in those days usually emphasized the mathematical side. Consequently the students learned the pernicious habit of hiding their ignorance under the

cloak of a mathematical formula. The popular conception of practical work in physics was that it consisted merely of accurate measurements involving the redetermination of constants previously obtained by other observers.

Maxwell endeavoured to dispel such views and to hold out a high ideal of the functions of a university laboratory. This is evident from his inspiring inaugural address :—

> "This characteristic of modern experiments—that they consist principally of measurements—is so prominent that the opinion seems to have got abroad that in a few years all the great physical constants will have been approximately estimated, and that the only occupation which will then be left to men of science will be to carry on these measurements to another place of decimals.
>
> "If this is really the state of things to which we are approaching our laboratory may perhaps become celebrated as a place of conscientious labour and consummate skill, but it will be out of place in the university, and ought rather to be classed with the other great workshops of the country, where equal ability is directed to more useful ends.
>
> "But we have no right to think thus of the unsearchable riches of creation, or of the untried fertility of those fresh minds into which these riches will continue to be poured. It may possibly be true that in some of those fields of discovery which lie open to such rough measurements as can be made without artificial methods, the great explorers of former times have appropriated most of what is

valuable, and that the gleanings which remain are sought after rather for their abstruseness than for their intrinsic worth. But the history of science shows that even during the phase of her progress in which she devotes herself to improving the accuracy of the numerical measurements of quantities with which she has been long familiar, she is preparing the materials for the subjugation of the new regions, which would have remained unknown if she had been contented with the rough methods of her early pioneers." [1]

Some of Maxwell's contemporaries seem to have held the view that experimental work was a pleasant pastime but hardly fitting the dignity of Wranglers. Conservative dons complained that mathematics together with natural science if studied during the short period of residence was more than one poor mind could bear. But Maxwell looked beyond the carping objections of his colleagues. He looked for a time when there should be a team of workers in the university laboratory toiling at great problems of investigation and forming themselves into a school of scientific criticism and technique.

But when he began his duties as Cavendish Professor there were but few students of physics, and these included several men of mature years who were research workers. We are told that only two students attended Maxwell's lectures on electrodynamics.[2] At the time when the Cavendish professorship was under discussion, he wrote to Rayleigh saying, " It will need a good deal to make experimental physics bite into our university

[1] *Collected Works.* Vol. II, p. 241.

[2] *A History of the Cavendish Laboratory.* London, 1910, p. 36.

system which is so continuous and complete without it." This proved to be only too true. He evidently felt the dead weight of tradition which hindered the progress of science at Cambridge. During the all too short period of his professorship, however, Maxwell infused fresh life into the Tripos examinations. As an examiner he set questions which provoked new lines of thought.[1] His published works introduced a wider and more philosophic view than had been known before, and indeed mark a new era in physical science.

Lord Rayleigh became Director of the Cavendish Laboratory after the lamented death of Maxwell in 1879. Rayleigh adopted the novel plan of tea-time intervals for discussion and so fostered the team spirit among his advanced students. This helped towards forming that community of research workers envisaged by Maxwell. During Rayleigh's five years tenure of office, systematic instruction in laboratory work was organized with great success by Glazebrook and Shaw.

Sir J. J. Thomson succeeded Lord Rayleigh as Cavendish Professor in 1884. Three years later the scientific world was roused to great enthusiasm by the detection of electro-magnetic waves by Hertz. These waves had been predicted by Maxwell's theory and so were of particular interest to students of the Cavendish laboratory. It was not long before experiments in these waves were going on in all parts of the laboratory.

In 1895 there were already a large number of research students including W. H. Bragg, Callender, Chree, Searle, Whetham.[2] In that year the university admitted research workers from other universities, and the first

[1] Campbell and Garnett. *Life of Clerk Maxwell.* London, 1882, p. 357.
[2] Cavendish Laboratory Supplement. *Nature*, 2981. Vol. 118, p. 42.

two such students were Rutherford from New Zealand and Townsend from Dublin.

The Cavendish Laboratory has been associated with the remarkable researches of Sir J. J. Thomson, Sir Ernest Rutherford, C. T. R. Wilson, Townsend, H. A. Wilson, O. W. Richardson, W. L. Bragg, Aston and many others. Sir J. J. Thomson realized as did his predecessors the value of practical physics not only as a means of research but also as an instrument of education. It is the scientific education of the humbler student as well as in the encouragement of research of the highest order that has made the name of the Cavendish Laboratory famous throughout the world.

40. *The Awakening to the Significance of Experimental Instruction in Schools*

Although there were isolated instances of laboratory instruction in schools long before the middle of the 19th century, yet the campaign for practical science teaching in schools did not begin until after the Royal Commissions of the '60's. Even when science lectures were tolerated in the great schools there were worthy men who thought demonstrations by the master quite unnecessary and practical work by the boys waste of time. There is a well authenticated story of Todhunter, who when he heard of a young master fixing up the famous "guinea and feather experiment" affirmed that demonstrations had a demoralizing influence on the boys. "They should," he said, "accept the master's word." The Special Commissioners appointed for the Public Schools

Act of 1868 required that the nine "great" schools over which their power extended should "provide and maintain laboratories and collections of apparatus and specimens."

The Devonshire Commission (see p. 91) after summarizing the previous reports explained that an effective grasp of the experimental sciences cannot be acquired from text books alone, and that no teaching can be regarded as satisfactory unless the learner becomes familiar with the methods of experiment and observation by practising them himself in field or laboratory.

The Sixth Report gives a full description of the design and equipment of chemical and physical laboratories at Rugby, Eton, Dulwich, University College School, Clifton, and Manchester Grammar School. There were also museums and botanic gardens at Clifton and Rugby.[1] Efforts were made at several of the great schools to give a certain amount of scientific instruction to all the boys. But owing to the large number of pupils and the few science masters, the teaching often took the form of lectures supplemented by experimental demonstrations. At Clifton, for example, all the boys attended a certain number of lectures and as a voluntary study boys were allowed to work in the chemical laboratory. The work there consisted mainly of qualitative analysis and the time spent varied from four to ten hours per week.[2]

From the evidence of many schoolmasters we gather that practical chemistry and more particularly simple chemical analysis formed the bulk of the laboratory teaching. There were some notable exceptions, yet we

[1] *Sixth Report of Royal Commission on Scientific Instruction.* C. 1279, 1875, pp. 36–49.
[2] *ibid.*, p. 104.

are forced to the conclusion that the practical work was often not experimental in the real sense. The lecture illustrations by the master tended to become merely verifications of the statements he had previously made. Presumably he was skilful enough to come through the ordeal with his reputation unscathed. The reports from certain schools are of considerable interest, and we will quote those parts dealing with laboratory instruction :—

University College School.

Session 1835–6. "The Upper VI class of pure mathematics was under the charge of Professor White, of University College. The same boys received instruction in natural philosophy: the first instance of the introduction of this subject into the school."

Session 1850–1. *Mr. Spencer's Report to Head-master.* "In natural philosophy, my classes are entirely experimental. During the past year we have read mechanics and hydrostatics, but in the previous session we had an experimental course on electricity, magnetism and electro-magnetism, besides a short course on the history and structure of the steam engine.

"In chemistry, we devote ourselves entirely to inorganic chemistry."

Communication from Professor G. Carey Foster, B.A., F.R.S. (December, 1870). "My class of practical chemistry in University College School began, I believe, in 1859.

"The course of instruction was of this kind. At the beginning of each lesson each *pair* of boys was

supplied with certain materials and apparatus, and as soon as they were all in their places, I described, as fully as I could, the experiments I wished them to make, but without telling them what result to expect. When they had done this, I made them examine, during the same or the next lesson, the products of the operations they had gone through.

"Throughout the course I purposely avoided the use of any text book as I specially wished that the knowledge the boys got in the class should be, as far as possible, the result of *their own* observations and experiments."

Rossall School.

"What departments of science are preferred? (*a*) By parents? Parents exhibit complete indifference to the whole subject, with the exception that they occasionally object to their sons devoting any time at all to it. (*b*) By the boys? Practical Chemistry. Also, in an unscientific manner, Natural History.

"What are the principal obstacles to the teaching of science in your own school?—(1) The great inducements held out by the universities for the study of classics and mathematics. (2) The unsettled state of opinion as to what is the aim of the study."

City of London School.

"How far are boys required to prepare their own apparatus for experiments, or to collect specimens during the intervals between lessons?—The boys belonging to the practical chemistry class entirely

prepare their own apparatus. They are encouraged to try experiments both at school and at home, and also to collect 'specimens.'

"Is there any difficulty in procuring competent Science Masters?—I have not experienced any.

"Where are the best obtained? Have they been specially trained for the work; and if so, in what does such training consist?—From the Government Science School, Royal School of Mines and Royal College of Chemistry, &c. &c."[1]

Stoneyhurst College.

"We teach the boys sufficient for them to pass the matriculation examination of the University of London. It is only the highest class that is specially prepared for this.

"This class (averaging about 16 in number and, perhaps 17 in age) has three hours weekly with a science master. They are supposed to get up in the intervals what they were taught in their last lecture. The text books in use are *Barff's Chemistry* and *Newth's Natural Philosophy*.

"There is a laboratory where the boys may make a few experiments, if they wish, under superintendence; but this has not been insisted upon."[2]

Christ's Hospital.

"On a day when practical work has to be done, the boys go first into the lecture room, and are shown the exact apparatus they have to use, and exactly how the experiments are to be made; then they

[1] *Sixth Report of Royal Commission on Scientific Instruction.* C. 1279, 1875, p. 139.
[2] *ibid.*, p. 141.

pass to the laboratory and make the experiments for themselves. In the practical teaching I have found the greatest advantage to arise from making the experiment as quantitive as possible. If they have nitric acid to prepare I give them a known weight of sulphuric acid, and make them calculate out and then weigh out the requisite quantity of nitrate of potash. In studying hydrogen I have made them reduce a known weight of oxide of copper and weigh the water obtained; this gives a definite interest to the experiment; they appreciate the quantitative nature of the reaction; it affords a most valuable check on the care and accuracy with which the experiment has been made, and excites a spirit of emulation to obtain the best results." [1]

Taunton College School.

"In the laboratory each boy learns the reactions of the metallic and non-metallic bodies. Mixtures are then given of progressive difficulty, the composition of which the pupil detects by his own judgment. High value is attached to the working out of problems, which appear to be a good test of scientific ability. Upon the senior boys is urged the importance of reading scientific books, so that they may acquire mental independence, and not remain a mere shadow of their teacher. Special opportunity is given to all the boys out of school for discussing any difficulties they may encounter. The Botany lectures include dissection and schedule writing, with practice in classification and description." [2]

[1] Sixth Report, p. 144. [2] *ibid.*, p. 199.

The examples we have chosen are of those schools where science flourished. There were many smaller schools where no science teaching of any kind was given, and many where the laboratory work was of a meagre and unsatisfactory kind. But in the last decades of the 19th century there grew up a body of opinion on the value of science teaching and particularly of laboratory instruction in schools. Huxley had urged the enrichment of the elementary school curriculum by the introduction of science teaching. The School Boards had made valiant attempts to foster such teaching. A system of experimental instruction had gradually evolved in the universities. The two lines of thought now converged towards the secondary schools.

41. *The Heuristic Method*

The question of practical science teaching was investigated by a Committee of the British Association which issued its report in 1889. The guiding spirit in this committee was Professor H. E. Armstrong who has worked zealously for the introduction of the experimental teaching in schools.

Armstrong advocated a system of teaching in which the pupil should discover things for himself. This became known known as the heuristic method.[1] Armstrong's experience with students at the City and Guilds of London Institute, Finsbury, led him to deplore the lack of early preparation and to insist on the importance of science as an indispensable part of the school course.

[1] Greek, Heurisko = serving to discover.

He urged that beginners even at the elementary school should be put into the position of original observers. He says :—

> "It is in no sense mere opinion on my part but a conviction gradually forced upon me and established beyond all doubt by actual trial and observation during many years past, that the beginner not only may, but must be, put absolutely in the position of an original discoverer ; and all who properly study the question practically are coming to the same opinion. I find young children are delighted to be so regarded, to be told that they are to act as a band of young detectives.
>
> "It is of no use for the teacher merely to follow an imaginary research path ; the object must ever be to train children to work out problems themselves and to acquire the utmost facility in doing so. Of course, the problems must be carefully graduated to the powers of the scholars and they must be insensibly led ; but do not let us spoil them by telling them definitely in advance what to look for and how to look for it ; such action is simply criminal.
>
> "The whole policy of the teacher's duty is summed up in one little word, yet the most expressive in the English language ; it is to train pupils to *do*. On this it is easy to base a simple test of competency." [1]

Taking as his ideal the words on the wall of the chemical theatre of the University of Leipzig, *Gott hat*

[1] H. E. Armstrong, *The Teaching of Scientific Method*. London, 1903, pp. 253–255.

alles nach Zahlmass und Gewicht geordnet, Armstrong made out a strong case for the early teaching of quantitative methods in schools. He even agreed that a balance should be regarded as an instrument of moral culture to be treated with care and reverence.

The British Association Committee justified the teaching of science because of its disciplinary value. They stated that a large body of experience proves that a well arranged course in physical science affords more than any other subject an "effective and attractive method of training the logical faculties." Such a course, they affirmed, develops the powers of accurately ascertaining facts and of drawing correct inferences. They insisted that science should be taught as a branch of mental education and not merely as useful knowledge. In this way, they claimed that science teaching would arouse those mental qualities which are "frequently deadened by the exclusive study of languages, history and mathematics."

The Committee pointed out that the scientific method of investigating nature consists in observing, experimenting, measuring and framing hypotheses. They claimed that science teaching, if it is to have any value, must involve all these activities. Chemistry, they said, is particularly well adapted for such instruction.

Professor Armstrong set on foot an active propaganda for heuristic science teaching in schools of all grades. He continually emphasized that a school laboratory should not be a treasure house of mysterious apparatus but an ordinary workshop with benches and tools, balances and simple devices, by which the pupils could carry out their investigations. There can be no doubt that Armstrong's writings brought about profound

changes in school science teaching. All would agree that the spirit of investigation is the urge to activity characteristic of the scientific life. To enable the young pupil to face problems and devise his own methods for wresting secrets from nature is surely a magnificent ideal. Unfortunately the disciples of Armstrong went too far. They regarded practical work in the school laboratory as an end in itself. Schoolmasters justified the most arid laboratory exercises by claiming that they inculcated "accuracy of observation." They were afraid to tell their pupils anything, and the unfortunate young investigators often gained nothing from their work in the laboratory but a marked distaste for the subject. The over emphasis on method and the ignoring of the importance of the content has done much to bring heuristic teaching into disrepute.

Chapter IX

TWENTIETH CENTURY DEVELOPMENTS IN SCHOOL SCIENCE

42. *The Attitude of the Board of Education towards Science in Secondary Schools*

THE Royal Commission of 1895 recommended the establishment of a central Education authority. This was effected in 1899 by the Board of Education Act.[1] The subsequent Acts of 1902 and 1903 abolished School Boards and empowered the local authorities to promote secondary education and to build new schools. Previously these authorities had been allowed to aid technical and science instruction only. The curriculum of the schools has been determined to a large extent by the Parliamentary grants which have undergone successive modifications.[2] At first there were grants for individual subjects, and the tradition of the old organized science schools led in many cases to an over emphasis on science teaching. Moreover, many technical institutes were taken over at this time by the local authorities and converted into secondary schools.[3] In these schools, as we should expect, science was given an exalted place.

[1] 2 Edw. VII, C. 42.

[2] *Board of Education Report for* 1906 (Cd. 3270), deals with the relationship between state control and individual endeavour.

[3] *ibid.*, p. 55.

Early inspections conducted by the Board revealed unsatisfactory teaching in the smaller endowed schools, and exclusive attention to grant-earning subjects in the newer schools. Accordingly, the Board abolished the grants for individual subjects and gave a single grant for an approved four years course.[1] A secondary school was defined as a "day or boarding school offering to each of its scholars up to and beyond the age of sixteen a general education, physical, mental and moral, given through a complete graded course of instruction of a wider scope and more advanced degree than that given in elementary schools." The approved subjects were defined as :—

1. English language and literature together with Geography and History.
2. At least one language other than English.
3. Mathematics and Science, both theoretical and practical.
4. Drawing.[2]

In this way science became a necessary part of the curriculum of every secondary school in receipt of grants from the Board. Considerable freedom in the drawing up of syllabuses has been allowed. But both the time spent and the range of the science teaching have been subject to the approval of the Board. The Code of 1904 stated that :—

> "Instruction (in secondary schools) must be given in at least two distinct branches of science, for each of which adequate laboratory accommodation, &c., must be provided. It is not necessary

[1] *Regulations for Secondary Schools.* 1904–5 (Cd. 2128), pp. 6–13.
[2] Board of Education, *Report.* 1903–6 (Cd. 3270), p. 46.

> that the same branches of science should be studied in each year of the course, but the selection should be such as to secure continuous and progressive instruction in science suited to the special circumstances of the school. Where subjects other than chemistry and physics are taken in the 1st and 2nd year of the course, the instruction in these years should include in chemistry and physics such instruction as may be made necessary for the proper study of the selected subjects." [1]

No further regulations as to Science were issued until 1917, when we find the following addition :—

> "The instruction in science must include practical work by the pupils. For girls over 15 domestic subjects, as needlework, cookery, laundry work, housekeeping and household hygiene may be substituted partially or wholly for science and for mathematics other than arithmetic." [2]

Thus the official mind thought it necessary to make specially lenient provisions for girls. The caution shown by the Board in securing a balance of the curriculum meant that Science no longer enjoyed a privileged position. Before the Cockerton judgment, when financed by the powerful School Boards, it seemed as if Science was about to be proclaimed as Herbert Spencer prophesied, "highest alike in worth and beauty." But the Cinderella of the curriculum enjoyed but a brief triumph. The regulations of the new Board of Education,

[1] Parliamentary Papers. 1904, Vol. 75, p. 551.
[2] Do. 1917–1918, Vol. 25, p. 127.

while not relegating science to the background, at least made her take a humbler place.

43. *Progress of Science Teaching in Elementary Schools*

In 1895 the Code made *Object Lessons* compulsory in Standards I, II and III of the elementary schools. This led to a considerable increase in the number of children taking Elementary Science as a "class" subject in the upper standards. At this time the curriculum of the training colleges was based on the assumption that all teachers would have to expound on the whole range of subjects taught in the elementary schools. Consequently science teaching became a necessity in the Training Colleges. In 1904 the subject was made compulsory and every college was obliged to have a suitably equipped laboratory. In the course of a few years the new regulations led to considerably better science teaching in the schools than in the days of the peripatetic demonstrators and the pseudo science of the object lessons. At the present time, however, science is not a compulsory subject in the training colleges.

In consequence of the Cockerton judgment the Board of Education found it necessary to legalize a system of *Higher Elementary* Schools. These schools received a higher grant than the ordinary elementary schools on condition that they provided a four years course for selected pupils between the ages of 10 and 15. The curriculum included compulsory science instruction, both theoretical and practical. The course usually

consisted of chemistry and physics, and the standard attained at the end of the course was that of the Junior Local Examinations. Indeed, the pupils for these schools often took these Examinations so that the whole trend of the curriculum approximated to that of the secondary schools.

However, there still remained the bulk of the elementary schools, where the pupils left at the age of 14. Science teaching in such schools has always been insisted on by the Board. But no detailed syllabuses of instruction have been prescribed and the Board has welcomed experiments in the devising or working of schemes.[1] The result has been the development, within recent years, of very effective methods for the teaching of Science to children whose school life is so short.

The general principle has been to abandon the academic method of approach to the sciences and to avoid the usual classification of the subject matter into chemistry, botany, heat, light, sound, electricity, etc. It has been felt that boys and girls in the elementary schools may acquire a sound working knowledge of a wide scope of phenomena connected with their daily experiences by such a course. In many cases the schemes consist largely of practical work demanding very little theoretical knowledge. It has been found possible for boys from 11 to 14 to deal with the mechanism of electric bells, switchboards, electric motors, air pumps, hot water supply, etc., in a workmanlike manner. Sometimes the science teaching is linked with woodwork, metal and leather work instruction.

[1] See for instance, *Some Experiments in the Teaching of Science and Handwork in certain elementary schools in London*, No. 36, H.M. Stationery Office, 1920; and *Rural Education*, No. 46, H.M. Stationery Office, 1926.

In one school visited by the present writer, the science master gives a course of lecture and demonstration lessons covering a range of topics in simple chemistry, physics and hygiene, and the boys go through a course of model making which involves practical mathematics and the application of principles learnt in the theoretical lessons. Each boy works at his own particular problem, so that many different activities are in progress at the same time. The scheme has already achieved considerable success.

Some interesting developments in science teaching have come from the schools under the London County Council. In addition to the ordinary elementary schools, the Council, in 1910, organized a system of *Central Schools*. These schools were intended for specially selected children of eleven years, who would be able to take advantage of a four years course having a commercial or industrial bias. Thus, while the leaving age in ordinary elementary schools was fixed at fourteen, pupils were able to stay after this age at the central schools. Consequently, the central schools have provided a more advanced curriculum.

In spite of the leaving age in ordinary elementary schools being fourteen, it has been found possible to introduce some valuable science teaching. No complaints as to lack of mathematical equipment on the part of the pupils or shortness of time ought to hinder what is an integral part of every child's education. In the schools under the London County Council, nature study is taught in the lower standards and in girls' schools hygiene is often taken. In the boys' schools, model and instrument making is taken in addition to simple laboratory work in elementary chemistry and

physics. Such practical work includes exercises in weighing and measuring, and simple manipulations in mechanics, heat, chemistry and electricity. In the Central Schools with an industrial bias, as much as five hours per week are allotted to Science in some cases.[1]

It is impossible to form a correct estimate of the nature of the science teaching from a mere perusal of the schemes of work in use. The value of science teaching depends so much upon the teacher's individuality and hence on his selection of topics for special emphasis. In the opinion of the present writer the schemes in use in many of the elementary schools are too comprehensive. When the content of the subject is so important it is a great temptation to draw up syllabuses covering a large range for fear of excluding topics which are regarded as having special "educational value." Nevertheless, the choice of subject-matter needs careful selection, and in the elementary schools the teacher would do well to adopt some scheme in which the work be complete in itself instead of giving a smattering of science on the conventional lines which is of very little value when the boys and girls leave school at the age of fourteen.

Much good has resulted from the improvement of science teaching. The history of the elementary schools has shown that since the time when the curriculum was enriched by the inclusion of literature, elementary science and the elements of algebra and geometry, the pupils have achieved better results in the three R's than when these subjects formed the entire content of the curriculum. The disappointing results of continuous

[1] *The Teaching of Science in Elementary Schools of the London County Council.* London, 1923, p. 3.

grind at the merely instrumental subjects was but another instance of the law of diminishing returns.

44. *External Examinations*

The problem of examinations is one which affects the secondary and public schools acutely. From 1902 onwards, the Board of Education Inspectors found that school authorities showed dissatisfaction with the examination system. The Inspectors themselves felt that examinations were leading to over-pressure and that the requirements of long syllabuses hindered the reform of teaching methods. Consequently, in 1904, the Board prohibited the presentation of pupils under 15 years of age for any examination other than one for the whole school. The whole question of examination was investigated by a consultative committee, whose Report was issued in 1911.[1]

As a result of the recommendations of the committee and after prolonged discussions, fourteen examinations were devised or modified between 1917 and 1919 in accordance with the suggestions of the Board. Of these, seven known as First School Examination are for pupils of about 16 years. In 1917 the Board set up the Secondary School Examination Council as an advisory body.

For the First School Examination the Board divided the subjects into three main groups, in each of which a choice of subjects is allowed. (i) English subjects; (ii) Languages; (iii) Mathematics and Science, and (iv)

[1] *Report on Examinations in Secondary Schools.* 1911, Cd. 6004.

a subsidiary group, consisting of Drawing, Music, Handwork, etc. Now when applied to existing examinations, the group and not the individual subject became the unit by which success or failure was determined. Thus it is possible for a candidate to pass in group (iii) by satisfying the examiners in mathematics without presenting himself in a science subject. Although the Board made science teaching compulsory in all grant earning Secondary Schools, yet the fact that a science is not compulsory in the First School Examination has led to a certain neglect of the subject in schools where Latin is taken, as this subject, when included in the language group, becomes an alternative to science in group (iii). The Secondary School Examination was intended to test the result of two years specialization, and hence science subjects were not compulsory except in the science and mathematics groups. It is of interest to note that the Civil Service Commission introduced a paper in general science for the examination for clerks to the Surveyor of Taxes in 1915, and in the examination for the Diplomatic Services in 1917.

In 1917 the Board of Education inserted a chapter in the Regulations for the recognition of *Advanced Courses*,[1] for the upper forms of secondary schools. The planning of the course is left to individual schools, but the schemes have to be approved by the Board before the special grants can be claimed. The work is intended to extend over two years for pupils who have passed a First School Examination. One of the recognized groups is in Science and Mathematics. The encouragement given by the Board to this advanced work has acted as a stimulus to the staff of schools

[1] First indicated in Circular 826, 1913, and modified in 1921 and 1922.

to bring their pupils up to a higher standard of work.

45. *Report of the Prime Minister's Committee on Natural Science*

In 1916 a Committee was appointed "to inquire into the position of Natural Science in the education system of Great Britain." The Chairman was Sir J. J. Thomson, and witnesses who gave evidence represented the opinions of the Board of Education, the various teachers' associations, the medical profession, employers of industry and the Conjoint Board of Scientific Societies. The Report which was published in 1918, reviewed every phase of scientific education from the University to the elementary school. The Committee began their deliberations when the country was in the throes of the Great War, a time when the daily papers reflected public opinion in deploring England's neglect of science. There was a widespread demand for education in science, and the nation having learnt the necessity of science in time of war was ready to admit its value in the longed-for period of peace.

We may summarize the principal conclusions as follows :—

> 1. That science should be included in the general course of education for all pupils in Public and other Secondary Schools up to the age of about 16, and that this general course should be followed by more specialized study whether in Science or in other subjects.

2. That the elements of Natural Science should be a necessary subject in the entrance examination of Public Schools and that due weight should be given to this subject in the entrance scholarship examinations to Public Schools.

3. That the science work for pupils under 16 should be planned as a self-contained course, and should include, besides Physics and Chemistry, some study of plant and animal life.

4. That more attention should be directed to those aspects of the sciences which bear directly on the objects and experience of everyday life.

5. That in the First School Examination all candidates should be required to satisfy the examiners both in Mathematics and in Natural Science.

6. That in this examination there should be co-operation between the teachers and examiners, and weight should be attached to the pupil's school record.

7. That many more scholarships are needed to enable technical students to pass on to the universities and also to enable boys from Junior Technical Schools (or their equivalent) and from Evening Schools to enter Senior Technical Schools.

8. That the First School Examination should be recognized by the General Medical Council as qualifying for entrance into the medical profession.

9. That an inquiry should be made as to the best methods of securing the services of scientific men

for the purposes of the State in permanent posts and otherwise.[1]

In the opinion of the present writer the most valuable part of the report is that dealing with the content of the school science course. Universities nowadays can be relied upon to carry on their good work. It is in the schools that the most difficult problems of teaching occur. The Report calls attention to the importance that has been attached to laboratory work since the heuristic method was preached in the closing years of the 19th century. We are warned, however, that there is a danger in over estimating the importance of laboratory exercises and that in many cases the time spent in such work is more than the results justify. The report points out that though the spirit of enquiry should permeate the whole science course, yet it is ridiculous to suppose that a boy can re-discover in his school hours all that he may be fairly be expected to know. The Committee therefore suggest that the demonstration lesson has its place, and that the time often spent in the repetition of laboratory exercises may be employed to some extent in the giving of definite informational lessons which shall bring home to the pupil some of the important applications of science in everyday life.

For pupils of 16—18 years the report suggests that time should be found for courses of lectures on the history of science as exemplified in the lives of great men, and that there should be some elementary treatment

[1] *Report of the Committee Appointed by the Prime Minister to enquire into the Position of Natural Science in the Educational System of Great Britain.* London, 1918, pp. 75–78.

of the growth of the leading concepts used in scientific thought. We are urged to regard science as one of the humanities, since it represents one of the great highways of human endeavour.

46. *The British Association and Science Teaching*

Although the history of science teaching is by no means identical with the history of opinions expressed on science teaching, yet, since teachers as a class are modest as to their own convictions and pathetically anxious to please, methods of instruction have been modified considerably by the recommendations of such a representative body of thought as the British Association.

In 1901, Section L, Educational Science, came into being. From that time onwards, the meetings have given rise to valuable discussions as well as official pronouncements on education in general and on science teaching. From the point of view of our present study the recommendations made from year to year afford an interesting account of the growth of an established opinion of the methodology and subject matter of science teaching.

Sir William Abney, in 1903, emphasized the importance of research as the life blood of science, and showed how science teachers must bring the research spirit into their teaching. Mr. W. M. Fletcher in the same year urged that the real discipline of scientific studies lies in the disentanglement of the essential from the accidental and in the building up of a coherent body of truth.

Professor Smithells, in 1906, deplored the narrow

outlook of many science teachers and advocated a course of science lessons figures based on matters of the household and of daily life.

In 1919 the question of science teaching was discussed fully by Sir Richard Gregory. He breaks away from the purely heuristic ideal so eloquently preached by Professor Armstrong, and suggests that training in experimental method may be given quite independently as a general science course. Thus he says :—

> "The chief reason for the narrow character of most science courses in schools is the small amount of time available and the demands made upon it in recent years by laboratory work. The substance of instruction has suffered from the concentration upon method, and the right adjustment of the conflicting claims of the two in a truly educational course has yet to be found. . . .
>
> "Let a broad, general course of science be followed independently of the intensive laboratory work in particular branches, designed solely to create and foster the spirit of experimental inquiry by which all scientific progress is secured. In this way it should be possible, even with the present limitations of time, to provide training in method, as well as wide knowledge. Before any reform of this character is possible, however, schools and examining bodies must revise their syllabuses so that the school course can be complete in itself and not, as seems generally to be assumed, merely preliminary work for pupils who intend to proceed to science degrees in universities." [1]

[1] British Association Report, 1919. Page 354 *et seq.*

In an illuminating Presidential address to the Educational Section at the Hull Meeting, 1922, Sir Richard Gregory again pointed out that science in schools must not be planned on the assumption that the pupils will proceed to a university course.

> "The science to be taught," he said, "should be science for all, and not for embryonic engineers, chemists or even biologists; it should be science as part of a general education—unspecialized, therefore, and without reference to prospective occupation or profession, or direct connection with possible university courses to follow. Less than three per cent. of the pupils from our State-aided secondary schools proceed to universities, yet most of the science courses in these schools are based upon syllabuses of the type of university entrance examinations—syllabuses of sections of physics or chemistry, botany, zoology, and so forth—suitable enough as preliminary studies of a professional type to be extended later, but in no sense representing in scope or substance what should be placed before young and receptive minds as the scientific portion of their general education." [1]

The "Science for all" advocated by Sir Richard Gregory, admirable though it sounds, raises a great number of questions. In practice, there is danger in such science becoming a mass of isolated facts from different fields. The broad outlook that the teacher may quite well possess as a result of long experience and fairly wide knowledge, is not necessarily transmissible

[1] British Association Report. 1922, p. 207.

to his pupils, however well the lessons may be arranged. The very immaturity of the pupils may be an insuperable difficulty. At the time of Sir Richard's address, however, the possibility of teaching "general science" was being discussed among the ranks of professional science teachers.

47. *Science for All*

In 1916 the Science Masters' Association proposed a course of General Science in response to the growing demand for a wider knowledge of science. At this time the Prime Minister's Committee were conferring together, and a pamphlet entitled *Science for All* was compiled by the Science Masters' Association at the request of this Committee. The movement for General Science has progressed considerably since the Oxford and Cambridge Joint Board introduced the subject in their School Certificate Examination. This affords another instance of the influence of external examinations.[1]

The Science Masters' Association has wisely affirmed that the essence of general science lies not in the syllabus but in its interpretation.[2] There we have the whole crux of the matter. The teaching of general science makes far greater demands on the personality and outlook of the teacher than elementary physics or chemistry taught along conventional lines. On paper, a syllabus of general science may look like a mere list of topics

[1] Papers in General Science are now given in the Army Entrance Examinations.

[2] *General Science.* London, 1924, p. 12.

covering a very wide range. It is only a skilful teacher who can give the unity that is required. But is his skill alone sufficient? Surely our efforts often fail because we confine our attention to the teacher and forget that the pupil's response is the essential factor in the educational process. The question of general science thus raises those psychological problems which have always beset the schoolmaster.

The idea behind the general science movement seems the elimination of academic, conventional teaching from the course for pupils up to the age of sixteen. It is desired that science should be part of the general education of boys and girls up to that age. This agrees with the recommendations of the Prime Minister's Committee. The Science Masters' Association have recently isued an outline syllabus of general science,[1] which includes the following studies.

Section I.

Principles of Mechanics as illustrated by simple machines and by falling bodies.
The meaning of Mass, Weight, Force and Energy.
Measurement of Time and Relative Position.
The general properties of Solids, Liquids, Gases.
Principles of Hydrostatics with Practical examples.
Production and Sources of Heat.
Ideas of Temperature and Heat.
Relation of Heat and Work.
Effects of Heat on Matter.
Water Vapour in the Atmosphere.
Transference of Heat—Domestic heating and ventilation.

[1] *General Science.* London, 1924, pp. 17–33.

Production and propagation of Sound.
Pitch, Loudness and Quality.
Production and propagation of Light.
Domestic Lighting.
Reflection, refraction and dispersion.
The Eye and simple Optical Instruments.
Elementary ideas of Magnetism.
Fundamental experiments of Electrostatics.
Effects of Electric Current.
Ohm's Law.
Primary and Secondary Batteries.
Current induction with the outlines of its application in the Dynamo.
Lighting—Transmission of power.
Conservation of Energy, dissipation and degradation of energy.

Section II.

Air, Water, Acids, Base Salts.
Combustion and Flame.
Minerals and Metals.
Elementary Chemical Theory.
The Lithosphere.
Crust of the Earth.
Hydrosphere.
Denudation.
Rocks.
Organic Rocks.
Soil, Minerals, Fossils.

Section III.

Living Matter.

Food and Fuel.
Simple Agriculture.
Plants—Natural selection—the simplest plants.
Animal Tissues, Protozoa.
Balance in Nature.
Evolution.
Human Physiology.
Elementary Hygiene.

Such an outline of general science treated broadly with reference to everyday applications and with due consideration for the interests of the pupil, takes us far from the rigid laboratory exercises of a generation ago. "Science for all" is still, however, under probation. Some of the schemes seem too ambitious in scope, some again assume a mature outlook happily rarely found in schoolboys of sixteen.

It is a matter of opinion whether a paper on General Science such as that of the Oxford and Cambridge Joint Board or any similar paper is the best means for securing that a scheme for the first school examination shall not consist merely of physics and chemistry. In a recent pamphlet [1] issued by the Board of Education, it is stated that only two schools out of thirty-nine presented boys for the General Science paper. Many Science teachers still confine the main part of their teaching to chemistry and physics until the stage of the first school examination, but the many "side lines" suggested by a General Science Scheme are dealt with, as occasion arises, in the discussion lessons. In this way

[1] *Report of an Enquiry into the conditions affecting the Teaching of Science in secondary schools for boys in England.* 1925.

it is possible to link up the more systematic teaching with topics arising in the pupil's daily experiences. Although "Science for all" has not been generally adopted, yet the movement is a sign of vigour among the professional science teachers and the very difficulties involved call forth the best that is in them.

A Scheme of General Science is suggested in a recent valuable report of the Board of Education dealing with the whole problem of post-primary education.[1] The syllabus suggested for modern schools or the senior classes of ordinary elementary schools is grouped round four main divisions.

1. The chemical and physical properties of air, water, or some of the commoner elements and compounds, the elements of meteorology and astronomy based on simple observations, and the extraction of metals from their ores.

2. A carefully graduated course of instruction in elementary physics and simple mechanics abundantly illustrated by means of easy experiments.

3. A broad outline of the fundamental principles of biology describing the properties of living matter including food, the processes of reproduction and respiration, methods of assimilation in plants and the action of bacterial organisms.

4. Instruction in elementary physiology and hygiene based on lessons in biology.

[1] *The Education of the Adolescent.* 1926.

The Board agrees that the teaching of science should be illustrated by reference to local environment and the trend of occupations with which the pupils are likely to be familiar. Considerable success has already been achieved in this direction.

Chapter X

THE PHILOSOPHICAL ASPECT OF EDUCATION IN SCIENCE

48. *Whewell and the Place of Science in a Liberal Education*

WE have seen how Whewell took up the cudgels on behalf of Cambridge at the time of the attacks of the *Edinburgh Review*. Whewell's balanced arguments were certainly the outcome of a consistent view of the aims of education for, like all other writers on education of his day, he judges the value of the various subjects of the curriculum from the point of view of the mental training they afford. The disciplinary view commended itself particularly to the austere Master of Trinity.

Whewell identifies a liberal education with the higher education provided for the upper classes, upon whom, he considers, the prosperity of the community depends. What a comforting and complacent view. He distinguishes between *permanent* and *progressive* studies.[1] Among the permanent studies he includes the ancient languages and established branches of mathematics such as geometry and mechanics. He applies the epithet progressive to the comparatively modern sciences of chemistry, botany, geology, etc. He considers that

[1] W. Whewell, *Of a Liberal Education*. London, 1845, p. 5.

both kinds of study should be included in a liberal education, but that the permanent studies must be taken first. Whewell would administer the powder before the jam.

One of the adverse criticisms of the writers in the *Edinburgh Review* was that Cambridge clung to old geometrical methods in the teaching of mathematics and neglected the newer analytical methods. Whewell is eloquent in his defence of geometrical methods as giving a training in reasoning. He tells us that analytic methods are mechanical. We are carried along "as in a railroad carriage entering in at one station and coming out of it at another, without having any choice in our progress in the intermediate space." [1] With geometrical methods, on the other hand, the student is not borne along in this comfortable fashion. He has to think out each step, to refer to what has already been proved and be able to survey the whole problem from different angles. Whewell concludes that the character of the reasoning involved accounts for the success of mathematics in having trained many eminent lawyers.[2]

When the mind of the student has been trained by the discipline of the permanent studies, he may give his attention to other subjects. Whewell considers that chemistry, though indispensable in the professional training for medicine, is not sufficiently systematized to form a good subject of study for students. Indeed there were but few general principles in chemistry at that time. He would have the young men learn the established sciences, such as astronomy and mechanics,

[1] *loc. cit.*, p. 41.
[2] W. Whewell, *Principles of English University Education.* London, 1845, p. 13.

where the conclusions can be rigorously tested. He maintains that criticism and argument belong to the mature philosopher and that students at the university must learn to submit to authority. If allowed to express their opinions instead of "quietly forming their minds for future action" [1] Whewell fears that they will become shallow and conceited. They must learn to judge the value of different hypotheses in those established subjects where there can be no difference of opinion. Hence the permanent studies must come first —Rules must be learnt before reasons.[2] Thus Whewell suggests that the various branches of mathematics and physics will supply the necessary discipline and that afterwards the student may proceed to chemistry, botany, etc. There is hint of the stern pedagogue behind all Whewell's arguments.

However, Whewell looks beyond the needs of the undergraduate and shows the value of a rich knowledge of science in a wide scheme of education. He maintains that the progressive studies, since they involve discovery, exert a profound influence upon education. He discusses at length the influence of the scientific discoveries of one period upon the intellectual outlook of the succeeding period.[3] He goes so far as to assert that "every great advance in intellectual education has been the effect of some considerable scientific discovery or group of discoveries."[4] As we should expect, the historian of the *Inductive Sciences* makes a great point of the careful study of the work of the great investigators

[1] W. Whewell, *Principles of English University Education.* London, 1845, p. 25.

[2] W. Whewell, *Of a Liberal Education.* London, 1844, p. 103.

[3] W. Whewel, *On the Influence of the History of Science upon Intellectual Education.* Lecture delivered at the Royal Institution, 1854. [4] *ibid.*, p. 6

of the past—he urges the introduction of questions on the history of science into Tripos examinations [1] and the giving of optional lectures at college on the historical development of science and on recent achievements in the progressive sciences.[2]

Whewell's words were as the voice of one crying in the wilderness. Men did not heed him because the great battle waged on behalf of science had not begun. Whewell's methodical arguments were not sufficiently resounding to make themselves heard in the great world outside the universities. Science needed a vigorous champion who could appeal to the multitudes. Such a man was Herbert Spencer.

49. *Herbert Spencer and Education for Complete Living*

Herbert Spencer (1820–1903) may be regarded as the philosopher of the scientific movement of the second half of the 19th century. He chose the term *evolution* to denote his hypothesis, which was an attempt to combine the notion of the derivation of existing plants and animals from simpler ancestors with that of the nebular theory of the universe. Spencer's extravagant generalizations found acceptance in an age that believed in progress and in its own sufficiency. His cry for the need of science in education found a ready response and his teachings were accepted, not from the intrinsic value of his arguments, but because of his recognized authority in other fields.

[1] *Of a Liberal Education*, p. 206. [2] *ibid.*, p. 213.

In his main work on education[1] Herbert Spencer begins with the question "What knowledge is of most worth?" In his customary fashion he refers back to primitive customs and describes the love of ornament and display shown by the Orinoco Indians. He then points out that the same love of display is shown in contemporary education. In the curriculum he explains that it is not what knowledge is of most worth that receives consideration but what knowledge is most imposing and most likely to bring applause. The shams of fashionable education, and in particular the accomplishments of young ladies, invoke his stern disapproval.

Herbert Spencer classifies the activities of life under five heads. (1) those which directly minister to self preservation; (2) those which by securing the necessaries of life indirectly minister to self preservation; (3) those activities which have for their end the rearing and discipline of offspring; (4) those which are involved in the maintenance of proper social and political relations; (5) those miscellaneous activities which fill up the leisure part of life.[2] Spencer's ideal education is one which shall train adequately in all these directions and thus prepare for complete living. He therefore maintains that the aim of education must be to give a "due proportion" between the degrees of preparation in each of the sciences. He applies his classification of the activities of life to the problem of the school curriculum.

Spencer distinguishes between the two values of every

[1] H. Spencer, *Education, Intellectual, Moral, Physical.* London, 1861.
[2] *ibid.*, p. 96.

intellectual acquirement, (1) knowledge, (2) discipline. In his discussion of the disciplinary value of scientific studies he takes refuge in the *asylum ignorantiæ* and baldly states that the acquirement of "facts most useful for regulating conduct involves a mental exercise best fitted for strengthening the faculties. It would be utterly contrary," he says, "to the beautiful economy of Nature, if one kind of culture were needed for the gaining of information and another kind were needed as a mental gymnastic."[1] Having disposed of an age-long problem in this simple manner he proceeds to show that the discipline of science is superior to that of ordinary education because of the *religious* culture which it gives. True science, he maintains, is religious because it gives the student a faith in unchanging relations "in the invariable connection of cause and effect and in the necessity of good or evil results."[2]

Herbert Spencer writes with such conviction that it is clear that he felt some moral effect resulting from the operation of physical forces. His writings reveal the characteristic 19th century attitude towards the inexorable laws of nature, but the confusion of ethical principles and the Rousseauan *discipline des choses* seems peculiar to him. Spencer's claim for science was primarily on the ground of its utility. This aspect no doubt commended itself more than any other at a time when the applications of science were receiving recognition on all sides. The very exaggeration with which he illustrated his arguments compelled attention.

[1] H. Spencer, *Education, Intellectual, Moral, Physical.* London, 1861, p. 46.
[2] *ibid.*, p. 51.

50. *Huxley and Retrospective Prophecy*

The course of science was pleaded in more reasonable tones by T. H. Huxley. Even the most conservative upholders of the classical regime were ready to admit that science is useful. Huxley sought to show that science is beautiful. The sunny side of his philosophy was revealed in his plea that children should be led to love nature and to follow her ways in joyous pursuit. Huxley's personification of nature leads him to regard nature as an educator. "Nature's discipline," he says, "is not even a word and a blow, and the blow first; but the blow without the word. It is left to you to find out why your ears are boxed . . . The object of education . . . is to make good these defects in nature's methods, and prepare the child to receive nature's education . . . without waiting for the box on the ear." [1]

Beginning with Voltaire's story of Zadig, the wise man of Babylon, Huxley shows that retrospective prophecy is a marked characteristic, nay, a definite function of astronomical science. He quotes the well-known statement of Airey that an eclipse of the sun was visible in Lydia on the afternoon of 28th May in the year 585 B.C. Huxley points out that such a statement cannot be verified, but that since the methods which astronomy uses when working forward lead to correct results, the same methods are trustworthy in working backwards to results not directly verifiable. This argument leads Huxley to his main thesis, namely, that the methods of retrospective prophecy are legitimate for other sciences since the method depends on what he calls the "fundamental axiom of the constancy of

[1] T. H. Huxley, *Collected Essays.* London, 1893, III, p. 85.

nature," which is the "common foundation of all scientific thought."[1]

Throughout his *Essays* Huxley emphasizes the different outlook resulting from a knowledge of science and hence he points out the need for science in education. He shows how the history of science reveals the growth of the conception of causality. The enormous development of scientific knowledge during the 19th century led Huxley and other men to rely too much on what they conceived to be the methods of science. While retrospective prophecy might lead to the reconstruction of events seemingly as real as those due to our immediate sense impressions, yet Huxley did not admit that the interpretation of past and immediate events depends on the use of certain instruments of thought which themselves require critical examination. It was not until after his time, however, that the serenity of men of science was disturbed by such doubts.

51. *The Discipline of Science*

We have seen that the arguments brought forward in support of science teaching have frequently been based on the supposed mental training that science affords. The evidence brought before the many Royal Commissions of the 19th century shows how great was the importance attached to the discipline of the different studies. The zealous partisans of science have affirmed that it trains the power of observation, judgment and

[1] "On the Method of Zadig." *Collected Essays.* London, 1893. Vol. IV, p. 12.

accuracy. Such statements are really based on what is known as the *Faculty Psychology*. According to this view, mental activity is supposed to involve certain elements or faculties such as observation, memory, discrimination and judgment. From time to time the presence of certain subjects in the school curriculum has been defended because of their supposed training of these faculties. Since there was no way of isolating these elusive faculties and estimating the extent to which they had been trained the arguments of these school masters could not be refuted. The importance of the *form*, that is, the act of observation or judgment, received undue emphasis while the material or content, such as mathematics, science or Latin, was regarded as relatively unimportant. The supposed training of the form apart from the content has been called *Formal Training*.

The Doctrine of Formal Training was implicit in the teachings of the philosophers of ancient Greece. Plato would have the Athenian youths learn music because such study brought harmony to the soul. Robert Recorde, writing in the 16th century, described Algebra as the "Whetstone of the Witte." Francis Bacon in his decisive manner advocated the study of mathematics because it "maketh a man subtle," and both wit and subtlety were supposed to be available for other material. It will be remembered that Bacon, like a physician, prescribed appropriate studies for the cure of every kind of mental infirmity. The general doctrine of Formal Training, however, was due to the philosophy of Locke. His teachings were incorporated with 18th century thought, and thus the roots of the belief in Formal Training are deep indeed.

The doctrine of faculties resulted in a crude nomenclature that has been responsible for much confusion. Apart from the hypostasis involved in the use of the terms judgment, observation, etc., it is evident that under these categories we may include activities of a vastly different nature. Thus the observation of the artist walking along Oxford Street and loving the winter sunset is different from that of a woman seeking for bargains displayed in the shop windows, and different from that of the taxi driver threading his way through the traffic. Yet the activity of each of these persons would be described as observation. Nevertheless, the advocates of Formal Training have urged that the power to observe is increased by observation and the power to judge by exercising judgment, thus implying that judging and observing are single activities independent of the material.

Modern physiological and psychological research, however, has shown that the crude doctrine of the formal training and faculties is untenable.[1] It is now realized that memorizing, observing and acts of volition are developed only in connection with specific ideals, actions and emotions. In order to effect a transfer of training from one department of mental activity to another there must be a linking of the specific ideas, actions and emotions with those of the general mental disposition. This linking is usually brought about by a conscious recognition of the elements common to the different mental activities. But the training value or *discipline* of the subjects of the curriculum has been

[1] C. S. Sherrington, *Integrative Action of the Nervous System*. W. Sleight, "Memory and Formal Training." *Brit. Jour. Psychol.*, IV, 1911. C. Spearman. "Qualified and Unqualified Formal Training." *Collected Papers*. Vol. III.

urged from the moral side. Stern pedagogues have subjects which are difficult, as in the old adage—spare the rod and spoil the child. Classical head masters have been seriously perturbed over the supposed inadequate discipline of scientific studies. The classical curriculum had a long tradition behind it, and the classicists, when they wanted to be rude, maintained that scientific education was an innovation. Schoolmasters clung to a belief in the purely disciplinary value of studies because otherwise they were driven to defend such studies simply on utilitarian grounds. Now the usefulness of any study could be discussed by parents and other laymen and submitted to the test of experience. On the other hand arguments based on the training value of certain studies always left a considerable margin for personal opinions.

The argument that classical studies owe their peculiar virtue to the intellectual difficulties involved was challenged by Huxley. In a delightful passage in which he exposes the follies of an exclusively classical curriculum by a *reductio ad absurdum* he says :—

"It is wonderful how close a parallel to classical training could be made out of palæontology . . . In the first place I could get up an osteological primer so arid, so pedantic in its terminology, so altogether distasteful to the youthful mind, as to beat the recent famous production of the head masters out of the field in all these excellencies. Next, I could exercise my boys upon easy fossils and bring out all their powers of memory and all their ingenuity in the application of my osteo-grammatical rules to the interpretation or re-construing of those fragments." [1] Although Huxley recognizes the value of the classics he proceeds to show that the

[1] Collected Essays. III, p. 97.

discipline of science may be just as rigorous as that of the classics, but that science possesses also a richness of content without which no education can be regarded as liberal.

The advocates of science as mental discipline have never gone so far as their classical opponents, for the content of science has always compelled attention. But it seems to me that there has been much confusion on the question of the teaching of scientific method. The term has been employed to denote the method used by the man of science himself. Francis Bacon, as we have seen, claimed that by using the inductive, i.e. scientific, method even the humblest investigator could discover the truth. The term is also used to denote the framing of hypotheses, the observing, experimenting and verifying that continually occur in every piece of scientific investigation. Books on scientific method are usually treatises which show how the processes of induction and deduction are used in scientific thought, and the conclusions are criticized according to the principles of logic.

Now the history of science shows that the great discoverers have not employed Baconian or any other single method in their investigations. Indeed many of the dazzling results seem to have sprung fully armed from the Jove-like brain. If we search among the works of Newton, for instance, we find merely a handful of general statements as to his method. The genesis of discovery is an unsolved and insoluble psychological problem. It is easy enough to exemplify the processes of deduction and induction after the discovery has been made or the conclusion formulated. Such demonstrations have their place as intellectual exercises in school work—but let us not delude ourselves that we are thus

initiating our pupils into the methods used by the great men of science in their own processes of thought.

Can we justify the teaching of science on the grounds of the mental discipline it affords? Yes, if we realize that mental discipline is something which must come from within and is not a harsh treatment imposed from without. What an individual perceives and understands depends on his experience and mental disposition. If the study of science is to mean anything more than gestures with a test-tube or the manipulation of a microscope, the pupil must acquire a particular mental disposition by submitting himself voluntarily to the influence of the great minds of the past. He must lose himself in the greater whole. He must become absorbed in the traditions of those who have gone before, and so realize, in some measure, the meaning of science.

52. *The Certainty of Science*

The belief in the inexorable character of mathematics may be traced back to Plato. During the revival of mathematical studies in the Middle Ages we find a child-like faith in the power of mathematics to interpret the realm of nature. Then in the post-Copernican period we find Kepler searching for the mathematical harmonies of the universe and declaring that God had waited since the beginning for an observer of His laws.

In the age of Galileo, Descartes, Spinoza, Leibniz and Newton the development of philosophy depended very largely on that of mathematics. In the philosophy

of Descartes we find the most unequivocal assertions about the power and certainty of mathematics. The vision which made Descartes turn aside from the irresponsible ways of youth was of the Angel of Truth who showed him that mathematics is the sole key needed to unlock the secrets of the universe. The correspondence between Descartes and Mersenne [1] shows that he convinced himself that mathematical laws were established by God in the beginning. Since God is perfect and His will invariable, Descartes claimed eternal truth for the conclusions of mathematics. For Descartes there were two worlds, the one a mathematical structure extending in space, the other a world of unextended thinking spirits. This dualism, of course, raised the problem of the relationship of mind and body. Descartes affirmed that through a part of the brain the unextended mind substance is able to enter into relationship with extended substance, the realm where mathematical certainty reigned supreme. In the Cartesian philosophy the place assigned to the mind was a relatively subordinate one, its function being merely the discovery of truth already existing in sublime isolation in the external world. This view led to the uncritical acceptance of many conclusions and as such had a powerful influence on the subsequent development of scientific thought.

The 17th century was marked by a vast growth of empirical knowledge. The experimental method had been preached by Francis Bacon and practised according to their own methods by Harvey, Gilbert, Boyle and Huygens. With this development of knowledge came a gradual recognition of the limitations of the field of scientific inquiry and a corresponding certainty as to the

[1] *Œuvres.* Cousin Edition VI, p. 108.

conclusions of science within that field. With Newton, the outstanding figure in this century of science, the great man and the great opportunity appeared together. The physical synthesis of Newton and his invention of a new mathematical instrument have directed the course of scientific inquiry until modern times. In the writings of Newton we find a clear distinction between the investigations of empirical science and questions of ultimate causality. Again and again Newton repudiates speculative hypotheses so that science becomes for him the exact formulation in mathematical language of the processes of the external world.

"Whatever is not deduced from the phenomena is to be called an hypothesis; and hypotheses whether metaphysical or physical, whether of occult qualities or mechanical, have no place in experimental philosophy."[1]

Newton gave a mathematical description of the way the moon and planets move, and thereby introduced a simplification into what had hitherto seemed the chaotic forces of nature. His law of gravitation received universal recognition. Belief in the simplicity of nature seems inherent in man. To the work of Newton, following on that of Galileo, we owe the concepts of mass, force and absolute space. These mechanical concepts were subsequently used in all scientific thought. The customary reliance on the certainty of mathematics led to an unquestioning belief in the physical principles mathematically formulated. The excessive veneration accorded to Newton is exemplified in the well-known tribute of Laplace, that Newton, besides being the greatest genius, was also the most fortunate

[1] Newton, *The Mathematical Principles of Natural Philosophy* (trans.), 3 vols. London, 1803, II, p. 314.

of men, for since there is only one universe it could fall to the lot of one man only to be the interpreter of its laws.

The great unifying principle of 19th century science was the doctrine of energy. The conception of energy had its roots far back in the dynamics of the 17th century, but the final formulation of the principle of the conservation of energy was due to the labours in the 19th century of Carnot, Joule, Kelvin and Helmholtz. The simplification introduced by this principle was one which could be easily grasped—and which brought with it a feeling of satisfaction and security.

The 19th century witnessed the flourish and decay of many theories of the ether. Thomas Young in the early years of the century was convinced that the ether passed freely through material bodies "as the wind through the grove of trees"; Kelvin was led to identify magnetic force with rotation in the ether. Maxwell posited an ether for the transmission of electro-magnetic effects and this ether he suggested might be identified with the medium required by the wave theory of light. The elastic solid theory of the ether, which was worked out by MacCullagh and others, seems to have so dominated the imagination of the physicists of the middle of the 19th century, that to Kelvin ether was the most certain of realities, and to Heaviside the science of electro-magnetics was founded upon the observations of "real Newtonian forces" with ether and energy as the only realities, all else being "moonshine."

Towards the close of the 19th century the prevalent idea, even in the universities, was that the great battle of science was almost won—certainly the achievements in physical science of Joule, Faraday, Kelvin and Maxwell, the triumph of the doctrine of energy, the enormous

development of chemistry and of the applications of science lent some support to this view. There was an air of finality, too, about the two great principles of invariance—the conservation of energy and the conservation of mass. The simplicity and grandeur of these doctrines was such that men felt inclined to survey with pardonable complacency the achievements of the past. But men of science were not allowed to slumber long. Already there were murmurs of criticism among the philosophers. In the closing years of the century, moreover, new natural phenomena were brought to light. In 1895 Röntgen discovered X-rays, a year later Henri Becquerel observed a new kind of radiation from Uranium salts. In 1898 the same type of activity was recognized in the compounds of Thorium by the Curies. Such discoveries were enough to rouse the soundest sleeper, and from that time a new era in the history of science began.

53. *The Ignorance of Science*

Although professed metaphysicians had long discussed the bases of knowledge, the first critical examination of the assumptions of a particular body of thought by a man of science was made known to the world in 1883 in the *Science of Mechanics* of Ernst Mach. In this work mechanics is treated not as a branch of mathematics but as one of the physical sciences. Mach investigates the historical development of the main principles of mechanics and so leads to his conception of science as *economy of thought*. "It is the object of science" he says "to

replace or *save* experiences by the reproduction and anticipation of facts in thought . . . rules for the reconstruction of a great number of facts may be embodied in a single expression . . . In nature, for instance, there is no law of refraction. The law of refraction is a concise compendious rule, devised by us for the mental reconstruction of a fact, and only for its reconstruction in part, that is on its geometrical side." [1] Thus for Mach the aim of science is not the search for absolute truth whatever that may be, and in freeing science from the entanglements of metaphysics he cleared the ground for the development of a fruitful scientific criticism.

The views of Mach were extended by Karl Pearson who showed clearly the consequences which follow from the restricted view of science as economy of thought. The work of Karl Pearson has done much to further the cause of scientific criticism in England.

"Scientific concepts," he says, "are, as a rule, limits drawn in conception to processes which can be started but not carried to a conclusion in perception. The historical origin of the concepts of geometry and physics can thus be traced. Concepts, such as geometrical surface, atom and ether, are not asserted by science to have a real existence in or behind phenomena, but are valid as shorthand methods of describing the co-relation and sequence of phenomena. From this standpoint conceptional space and time can be easily appreciated and the danger avoided of projecting their ideal infinities and eternities into the real world of perception." [2]

If we accept the function of science as a description

[1] E. Mach, *Science of Mechanics.* Eng. trans. London, 1893, pp. 481, 485.
[2] K. Pearson, *Grammar of Science.* London, 1892, p. 191.

of experience we are free from the old controversies about the outer world. We judge the conclusions of science accordingly as they are consistent within their own field. A scientific law is a generalization stated by the man of science as a means of summarizing his experience. Future generations will use the law as a means for further research or they will abandon it if it is no use. Thus the so-called laws of nature are made by man.

Science, however, does not consist of a mass of *ad hoc* hypotheses and unrelated laws. In the sense that man frames the generalizations, he makes the laws. But these laws can often be fitted into a logical scheme. indeed our minds demand that they *shall* fit into a logical whole, and we go on trying until we succeed. We have a deep-rooted belief in what Whitehead calls the Order of Nature. We are ignorant because we can only know the world in terms of our sense perceptions. But science is built up from the experiences of countless individuals. Our belief in the Order of Nature is based on those common elements abstracted from the experiences of ourselves and our fellow men. However, we must remember that the pronouncements of science are limited to the particular range of experience concerned, they are not statements as to universal truth but are merely supposals: if so-and-so happens then so-and-so follows. There is much virtue in "if." This particular view of science was recognized so long ago as 1867 by Kekulé, who, in a discussion on the atomic theory, said: "The question whether atoms exist or not has but little significance from a chemical point of view, its discussion belongs rather to metaphysics . . . From the philosophical point of view I do not believe in the actual existence of atoms . . . As a chemist, however, I regard

the assumption of atoms not only as advisable but as absolutely necessary . . . *whether matter be atomic or not, this much is certain, that granting it to be atomic, it would appear as it now does.*"[1]

We have seen how during the centuries in which mathematics was the only established science, no doubt was ever cast upon the certainty of its conclusions. Geometrical propositions were regarded as eternal truth and divine in their origin. Until the early part of the 19th century mathematics was regarded as, a priori, knowledge, and the other sciences became self-respecting as soon as they were on good terms with mathematics. After a time it was realized that Euclidean geometry is but one out of many possible geometries—that of Euclid simply fits in with the state of things to which we have been accustomed from our early childhood. The non-Euclidean geometries have been used in the theories of *Relativity* which entered the arena of public discussion during the period 1910–1920. The theory has shown that our traditional assumptions require examination. The theory has shown us, too, how the consistent "closed system" of physical science is undisturbed by those elements from the outside of which we are ignorant.

In our acknowledgment of the ignorance of science may we place any reliance on its predictions? A noble array of scientific prophecies at once comes to mind, the classic example of Halley's comet, the discovery of Neptune by Adams and Leverrier, Clerk Maxwell's prediction of electro-magnetic waves and the synthesis of complex carbon compounds worked out with the aid of structural formulæ before their preparation in the

[1] Quoted in I. Freund. *Study of Chemical Composition.* Cambridge, 1904, p. 624.

laboratory. Such predictions are examples of what Nunn aptly calls the *intellectual control* which science gives. Scientific knowledge is a structure of concepts and a description of phenomena in terms of those concepts. Within the boundaries thus marked out, science can predict and its conclusions are consistent.

Even when the conceptional instruments are at fault, the results may be of value. Thus the caloric theory in the hands of Black led him to regard heat from a quantitative standpoint and so to arrive at important numerical results. The same caloric theory was held by Carnot, but his investigations when further elaborated led to the enunciation of one of the most fruitful generalizations in physical science. At the present time the physicist chooses his conceptional instruments according to the particular problem on hand. Thus, in discussing the phenomena of double refraction in crystals he uses the suppositions of the elastic solid theory of the ether. He adopts the wave theory of light in describing the phenomena of interference. But he uses the quantum theory to account for the distribution of energy in the spectrum of a black body. Yet attempts to reconcile the wave theory and quantum theory are still under discussion. These considerations lead us to take a pragmatic view of scientific truth. We will use conceptual methods which work and refrain from any pronouncements as to final truth and certainty. As Heaviside once said: "A physicist may employ unrigorous processes with satisfaction and usefulness if he, by the application of tests, assures himself of the accuracy of his results."[1] The test applied is simply the criterion of usefulness.

[1] O. Heaviside. *Electro-magnetic Theory*, 3 vols. London, 1899, II, p. 9.

The progress of science involves continual change. Old theories that have out-worn their usefulness have to be discarded. Syntheses have to be broken up, analysed afresh, with the help of new knowledge these unite up into a syntheses simpler than the first. The process is a kind of intellectual metabolism. In the past there have been periods when the progress of science seemed to be but the steady acquisition of knowledge and the consolidation of fundamental principles. Then there have been periods of warfare, with the clash of divergent opinions, which have resulted in profound changes in outlook and method. Throughout these changes science has progressed by making her own weapons and her own plan of attack by which she has conquered vast territories from the region of the unknown.

Conclusion

AT the present time most teachers of science in school or university would have a ready answer to the question "Why is science taught?" It is quite likely that their answer would be couched in terms of the discredited faculty psychology, and they would claim that such teaching developed the habits of accuracy, judgment or observation. They might, however, emphasize the usefulness of science in our complex civilization, or they might claim to teach scientific method, each probably having different views as to what is included under that term.

These reasons which have been given over and over again have all emerged since the time when science teaching reached the self-conscious stage. That period may perhaps be placed at the middle of the 19th century. Now the science of the universities was for hundreds of years almost entirely Aristotelian. In the 14th and 15th centuries the physics of Aristotle was part of the conventional knowledge of the learned men of the time. The tradition of such teaching became established and so prevailed in the universities long after the experimental method had been practised in the greater world outside. With the growth of empirical knowledge in the 17th and 18th centuries there came a demand for science teaching. This was supplied, as we have seen, by small academies and by private teachers. In the late 18th and early 19th centuries the changed economic conditions brought about by the industrial revolution were

followed by the rising prosperity of the middle classes. The demands for science teaching became more insistent and resulted in the establishment of the Mechanics Institutes, night schools and systems of popular lectures on scientific subjects. Science teaching of a kind was thus established long before pedagogues and professors were ready with their reasons as to why the subject should be taught.

Questions as to the reasons for teaching science still disturb the equanimity of schoolmasters. The problems of the science master are naturally different from those which beset his colleagues because in science the boundaries of knowledge are continually changing. But it seems to me that teachers of science are still called upon to defend their subject because of the traditional attitude of the ordinary educated man. Now science is not yet part of conventional knowledge. That hypothetical individual, the average man, pretends at least to know a little Latin and Greek and to be qualified to give an opinion on modern poetry, on music, and on painting. He would blush if he pronounced incorrectly a name in classical mythology or was ignorant of the scores of the latest test match. Yet this individual would not mind expressing a complete ignorance of the simplest facts of science. There may come a time when he will be ashamed if unable to talk pleasantly on the principles of wireless telegraphy, of television, of the synthesis of indigo, or converse on the potency of the latest vitamin isolated. But that time is not yet. Science still needs her apologists.

The new outlook of modern science will eventually influence teaching methods. Naturally the study of recent developments belongs to the university course.

But even in schools some modifications are necessary. As Nunn has said, "The teacher cannot be absolved from the duty of facing and adopting some answer to the questions which scientific criticism raises."[1] Unfortunately the view that the aim of science is to give a final true account of reality is still held by many. In a recent discussion in the daily press on a challenge thrown down to Einstein by an American physicist, the writer remarked on the change in viewpoint necessitated by the theory of Relativity. Then came the note of malice: "If they should have to shift again, how amusing that will be." We constantly find this demand for finality in that section of the community known as the general public—not yet free from the oppressive generalizations of Victorian science.

If science teaching is to mean anything more than the acquisition of a few tags of knowledge and a certain skill in manipulation we must accord to science a place among the humanities. The teacher must try to give his pupils the conception of science as a process of development through human endeavour. He must avoid the dogmatic attitude shown in many elementary text books and help the pupils to gain some critical insight into the conclusions of science. The old dictum that science is exact measurement obviously requires modification, and the teacher of science must endeavour to make his pupils realize the limitations and the scope of physical measurements.

The human side of science is perhaps best introduced by a carefully selected historical treatment. Subordination of detail may be combined with an intensive

[1] F. Hodson, *Broad Lines in Science Teaching*. London, 1909. Article by Nunn, p. 72.

study of parts of the subject adapted to the outlook of the young student. The discipline of science, we have urged, must come from within. Some insight into the struggles and disappointments which have inevitably accompanied every great achievement will help them to realize at what cost new truth is given to the world.

Some Suggestions for Reading

Adamson, J. W.	A Short History of Education	Cambridge,	1919
Archer, R. L.	Secondary Education in the 19th Century	Cambridge,	1921
Arnold, Thos.	Miscellaneous Works	London,	1845
Armstrong, H. E.	The Teaching of Scientific Method	London,	1903
Do.	Pre-Kensington History of Royal Royal College of Science	London,	1921
Acland & Ruskin	The Oxford Museum	London,	1893
Buck, Geo.	The Third University of England	London,	1613
Burton, Robert	Anatomy of Melancholy	Oxford,	1621
Brougham, H.	Practical Observations on Education of the People	London,	1825
Do.	Objects, Advantages and Pleasures of Science	London,	1826
Burns, C. Deslisle	A Short History of Birkbeck College	London,	1924
Birchenough, C.	History of Elementary Education	London,	1920
Burtt, E. A.	Metaphysical Foundations of Modern Science	London,	1925
Broad, C. D.	Perception, Physics and Reality	London,	1914
Do.	Scientific Thought	London,	1923
Branford, Benchara.	Janus and Vesta	London,	1916
Comenius	Didactica Magna (Trans. M. W. Keatinge)	Oxford,	1896
Clarendon	History of the Rebellion	London,	1703
Copplestone, Ed.	Reply to Calumnies of Edinburgh Review	Oxford,	1810
Campbell & Garnett	Life of J. Clerk Maxwell	London,	1882
Collingwood, R. G.	Speculum Mentis	Oxford,	1924
Clifford, W. K.	Common Sense of the Exact Sciences	London,	1885
Campbell, Norman	Physics, the Elements	London,	1925

Desaguliers, J. T.	Course of Experimental Philosophy	London,	1734
Friend, John J. M. (trans.)	Chymical Lectures	London,	1712
Gilbert, W.	On the Magnet, etc. (trans.)	London,	1900
Glanvill, Joseph	Plus Ultra	London,	1668
Godwin, Wm.	Enquiry Concerning Political Justice	London,	1793
Gunther, R. T.	Early Science in Oxford	Oxford,	1923
Do.	Early British Botanists and Their Gardens	Oxford,	1922
Do.	Historic Instruments for the Advancement of Science	Oxford,	1925
Do.	The Daubeny Laboratory Register. 2 Vols.	Oxford,	1916
Harvey, Wm.	Anatomical Dissertation Concerning Motion of Heart and Blood in Animals	Frankfurt	1628
Herbert of Cherbury	Autobiography (4th Edition)	London,	1792
Hoole, Chas. (trans.)	Orbis Sensualium Pictus of Comenius	London,	1658
Do.	New Discovery of the Old Art of Teaching School	London,	1660
Harris, John	Lexicon Technicum	London,	1704
Hudson, J. W.	History of Adult Education	London,	1851
Hole, James	Essay on History and Management and Literary, Scientific and Mechanics Institution	London,	1853
Huxley, Leonard	Life and Letters of T. H. Huxley	London,	1903
Jones, Bence	Royal Institution	London,	1871
Jenks, E.	An Outline of English Local Government	London,	1894
Jevons, Wm. Stanley	Principles of Science	London,	1874
Knox, Vicesimus	Essays, Moral and Literary. 3 vols.	London,	1782
Little, A. G.	Roger Bacon—Essays contributed by various writers	Oxford,	1914
London, Wm.	Catalogue of the most Vendible Books in England	London,	1658

Locke, John .	. Essay Concerning Human Understanding	London,	1690
Do.	Some Thoughts Concerning Education	London,	1693
Do.	Of the Conduct of the Human Understanding . . .	London,	1706
Lyte, H. C. Maxwell	History of Eton College . .	London,	1875
Mullinger, James B.	Cambridge Characteristics in the 17th Century . . .	London and Cambridge,	1867
Do.	History of the University of Cambridge. 3 vols. . .	Cambridge,	1911
Mumford, A. A.	. Manchester Grammar School .	London,	1919
Maxwell, Cl. .	. Introductory Lecture on Experimental Physics . . .	Cambridge,	1871
Morgan, S. E. de	. Memoir of Augustus de Morgan .	London,	1882
Mach, Ernst .	. Science of Mechanics . .	English trans., London,	1893
Murray, R. H.	. Science and Scientists of the 19th Century	London,	1925
Mallet, Sir Charles	History of the University of Oxford. 2 vols. . . .	London,	1924
Needham, J. .	. Science, Religion and Reality .	London,	1926
Newman, Henry	. Idea of a University . . .	Oxford,	1852
Peacham .	. Compleat Gentleman . .	London,	1622
Petty, Wm. .	. Advice to Mr. Samuel Hartlib, etc.	London,	1647
Priestley, Jos.	. Essay on First Principles of Government	London,	1768
Priestley, Jos.	. Scientific Correspondence of .	N. York,	1842
Pachtler, G. M.	. Ratio Studiorum, etc. 2 vols. .		1887
Pattison, Mark	. Suggestions on Academical Organization	Oxford,	1868
Parkin, Sir George R.	Life of Ed. Thring. 2 vols. .	London,	1900
Pearson, K. .	. Grammar of Science, Pt. I. Physical	London,	1892
Poincaré, H. .	. Science and Hypothesis (trans.) .	London,	1910
Rashdall, Hastings	. Universities of Europe in the Middle Ages . . .	Oxford,	1895

Rowlandson, T. and Pugin, A. W. M.	Microcosm of London. 3 vols.	London,	1808
Singer, Charles	Studies in History and Method of Science. Vol. I.	Oxford,	1917
Do.	Do. Vol. 2.	Oxford,	1921
Sprat, Thos.	History of Institution Design and Progress of Royal Society of London	London,	1678
Snell, George	On the Right Teaching of Useful Knowledge	London,	1649
Sheridan, Thos.	British Education	London,	1756
Smith, Adam	Wealth of Nations	Edinburgh,	1863
Society for the Diffusion of Useful Knowledge	The Results of Machinery	London,	1831
Strutt, J. H.	John Wm. Strutt, 3rd Baron Rayleigh	London,	1924
Sadler, Michael	Evening Continuation Schools in England and Elsewhere	Manchester,	1907
Tillyard, A. I.	A History of University Reform	Cambridge,	1913
Tuckwell, T.	Reminiscences of Oxford	Oxford,	1900
Do.	Pre-Tractarian Oxford	Oxford,	1907
Wallis, John	Defence of Royal Society, etc.	London,	1678
Do.	In Collectanea Letters written in 1700 (Oxford Hist. Society)	Oxford,	1885
Wilkins, John	Mathematicall Magic	London,	1648
Worster, Benjamin	A Compendious and Methodical Account of Principles of Natural Philosophy	London,	1722
Wordsworth, Chr.	Scholæ Academicæ	Cambridge,	1877
Whewell, W.	Of a Liberal Education	London,	1844
Do.	Thoughts on the Study of Mathematics as part of a Liberal Education	London,	1845
Do.	General Bearing of Great Exhibition on Progress of Art and Science	London,	1852
Whitehead, A. N.	Principles of Natural Knowledge	Cambridge,	1919
Do.	The Concept of Nature	Cambridge,	1920

Whitehead, A. N.	Principle of Relativity . .	Cambridge,	1923
Do.	Science and the Modern World .	Cambridge,	1926
Wall, Martin .	Dissertation on Select Subjects in Chemistry and Medicine .	Oxford,	1783
Ware, F. . .	Educational Foundations of Science and Industry . .	London,	1852
Willis, R. and Clark, J. W.	Architectural History of University of Cambridge . . .	Cambridge,	1886
Watson, Foster .	Tudor School Boy Life—the Dialogues of Vives . .	London,	1908
Do.	Beginnings of the Teaching of Modern Subjects in England .	London,	1909
Various Contributors	History of Cavendish Laboratory	London,	1910

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